Municipal Water Treatment Plant Energy Baseline Study

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Table of Contents

Executive Summary **Exec-1**
1. Industry Background **1**
2. Current Regulations and Regulations Under Development **3**
  2.1 Overview 3
  2.2 Microorganisms 3
  2.3 Stage 2 Long Term Enhanced Surface Water Treatment Rule (LT2) 4
  2.4 Disinfection By-Products (DBP) 5
  2.5 Stage 2 Disinfectants and Disinfection Byproduct Rule (DBP 2) 5
  2.6 Inorganic Chemicals, Organic Chemicals and Radionuclides 5
  2.7 National Secondary Drinking Water Regulations 6
3. Water Systems **7**
  3.1 Typical Characteristics of Groundwater 7
  3.2 Typical Treatment for Groundwater 7
  3.3 Typical Characteristics of Surface Water 8
  3.4 Typical Treatment for Surface Water 9
  3.5 Electrical Consumption for Typical Groundwater and Surface Water Treatment Plants 10
4. Treatment Techniques **12**
  4.1 Conventional Treatment Techniques for Surface Water Treatment Facilities 12
  4.2 Other Treatment Techniques 13
  4.3 Disinfection Techniques 16
    4.3.1 Chlorine Gas 16
    4.3.2 Chlorine Dioxide 17
    4.3.3 Sodium Hypochlorite 18
    4.3.4 Chloramination 19
    4.3.5 Ultraviolet Radiation 19
    4.3.6 Hydrogen Peroxide Treatment Technique 21
    4.3.7 Ozonation 21
    4.3.8 Ozone/UV 23
    4.3.9 UV/Hydrogen Peroxide 24
    4.3.10 Ozone/Hydrogen Peroxide 24
5. Summary of Survey of Current Utility Practices and Plans **26**
6. Strategies for Compliance with Regulations Under Development **31**
7. Comparison of Disinfection Techniques **33**
8. Baseline Design, Energy Efficiency Measures and Incentives **38**
  8.1 Baseline Design, Energy Efficiency Measures and Incentives for Treatment Techniques 38
  8.2 Baseline Design, Energy Efficiency Measures and Incentives for Equipment Choices 38
9. Conclusions **43**

Appendix:

A: U.S. EPA Drinking Water Regulations and Guidance
California Department of Health and Services
B: Survey of Municipal Water Suppliers and List of Suppliers Contacted

Tables

Table E.1. Baseline Design and Example Energy Efficiency Measures.. E2
Table 3.1. Electricity Requirements for 'Typical' Surface Water Treatment Plants 10
Table 3.2. Energy Consumption for 'Typical' Water Treatment.. 11
Table 5.1. Summary of Current Utilities' Operations.. 29
Table 7.1. Criteria for Comparison of Disinfectants.. 34
Table 7.2. Estimated Energy Consumption for Ozone Generation... 35
Table 7.3. Estimated Power Consumption for 5.2 MGD Membrane Water Treatment Facility 36
Table 8.1. Baseline Design and Example Energy Efficiency Measures 42
Table 9.1. Comparative Energy Use for Various Treatment Techniques 43

Figures

Figure 3.1. Schematic Diagram of a Typical Groundwater Treatment Plant.................................... 8
Figure 3.2. Schematic Diagram of a Typical Surface Water Treatment Plant.................................. 9
Figure 4.1. Mass Transport in Membrane Treatment 15
Figure 5.1. The Number & Percentage of Survey Respondents Treating the Source Water Identified 27
Figure 5.2. The Number & Percentage of Survey Respondents Providing the Identified On-Site Treatment 27
Figure 5.3. The Number & Percentage of Survey Respondents Using the Identified Method of Disinfection 28
Figure 5.4. The Number & Percentage of Survey Respondents Using the Identified Energy Efficiency Measure 28

Executive Summary

Nationwide, approximately three percent of the total electricity generated by the electric power industry is consumed by publicly owned water and wastewater industries. By 2016, when additional federal and state drinking water treatment regulations will be in effect, the energy used for water treatment is expected to be at more than 100 million kWh per day, an increase of 30% from 1996 levels.

PG&E recognizes the significant amount of energy used by the water treatment industry. This document was developed as one element in the utility's programs to provide information about the industry, to encourage incorporation of energy efficiency into the design and operation of water treatment facilities, and to provide a basis for PG&E to offer a financial incentive to utilities that implement technology or equipment that exceed the energy efficiency of the 'baseline' or 'standard' technology or equipment.

Irrespective of the economic advantages of lowering electrical consumption, it is understood that water treatment utilities have other objectives that must take precedence over energy savings. Those objectives include:

- Maintaining water quality
- Meeting daily consumer demand
- Providing water supply in emergency situations such as fire and power outages

There are two primary sources of water for public drinking water supply: groundwater and surface water. Californians consume 6.1 billion gallons of water per day of which 2.8 billion gallons per day are from groundwater and 3.3 billion gallons per day are from surface water sources. Current and pending state and federal regulations that specify the treatment of drinking water are substantially different, depending upon the source of the raw water.

Currently, 80% or more of a water utility's energy consumption is typically used for pumping water. However, the water treatment industry is in a major transition in which new regulations impose more stringent limits on the allowable concentration of impurities. In addition, the regulations impose requirements to control the concentration of impurities not previously required to be controlled. For many treatment facilities, the regulations are likely to require the use of relatively new treatment techniques for treating drinking water such as ozone, ultraviolet radiation, hydrogen peroxide, chlorine dioxide or membrane filtration. These treatment techniques require significantly greater use of electricity than treatment techniques that are typically used at the current time. The water treatment industry is investigating which treatment technique and for many facilities, which combination of treatment techniques will provide compliance with the new regulations. Each treatment technique is effective in removing different contaminants, produces different by-products, and leaves different residuals, if any. They are not simply interchangeable treatment options. The source of the water to be treated, the specific contaminants in the water and their concentration, existing treatment processes and other considerations will guide which of the treatment techniques will be most applicable for complying with the new treatment requirements. Energy efficiency programs that target the water treatment industry should address both pumping water and the treatment techniques.

This study presents information about existing and pending regulations for the treatment of drinking water, typical treatment techniques and the new treatment techniques expected to be used to comply with the new regulations. Also, this study identifies some energy efficiency measures applicable to the new treatment techniques that qualify for an incentive payment under PG&E's New Construction Program. The baseline and the energy efficiency measures are summarized in Table E.1. Additional energy savings measures for the new treatment techniques may be identified by a detailed investigation of the new technologies.

Table E.1. Baseline Design and Example Energy Efficiency Measures for PG&E's New Construction Program

Category		Baseline Design	Energy Efficiency Measure Example	New Construction Program Incentive? Y - N - Maybe
Treatment Technique				
	Screening Aeration Coagulation and Flocculation Sedimentation Granular Filtration Ion Exchange	EPAct motors	Premium efficient motors	Y
	Membrane Filtration	EPAct motors	Premium efficient motors	Y
		Limited pretreatment	Coagulation/Flocculation/Sedimentation	Y
	UV Disinfection	Medium pressure lamps	Low pressure lamps	Y
	Ozone	Fine bubble diffusers	No	N
		Ozone generation starting from air	Ozone generation starting from LOX	Maybe
	Ozone/Peroxide	same as ozone	same as ozone	same as ozone
	UV/Peroxide	Medium pressure lamps	Low pressure lamps	Y
	Raw Water Pumping	EPAct motors	Premium efficient motors	Y
		Throttling or by-pass	VFD	Maybe (1)
	Finished Water Pumping	EPAct motors	Premium efficient motors	Y
		High pressure for entire system	Booster pump for high elevation customers	Y
		Throttling or by-pass	VFD	Maybe (1)
Equipment				
	Motors	EPAct motors	Premium efficient motors	Y
		Constant speed	VFD	Maybe (1)
	Pumps	Standard components	High durability components	Y
		Standard interior surface	Liner to reduce friction	Y
	Booster pump	High distribution system pressure	Localized booster pump	Y
	Blowers	Constant speed, multi-stage	High efficiency single stage	Y
	Compressors	Modulating	Load/unload with receiver	Y
		No sequencer	Sequencer	Y
	Valves	High head loss	Low head loss valve or VFD	Y
	Water storage capacity	Standard capacity	Increased storage capacity	Maybe
	Information and controls	Limited data collection & controls	Integrated data collection & control system	Y
	Piping	Standard interior surface	Liner or coating to reduce friction	Y
	Lighting	Title 24	Motion detector to activate lighting	Y
			Multi-level switching	Y
			Use of day-lighting	Y
			Photocell to control exterior lighting	Y

(1) Unless a variable fluid flow is required by the process.

1. Industry Background

Nationwide, approximately three percent of the total electricity generated by the electric power industry is consumed by publicly owned water and wastewater industries. In 1996, an estimated 78 million kWh/day of electricity was used for water supply and treatment in the United States. By 2016, the amount of energy consumption is expected to increase to more than 100 million kWh/day. This increase is expected as a result of increases in demand for water and the use of energy intensive technologies needed to comply with new federal and state drinking water regulations. Energy costs typically range from 20% to 60% of a drinking water utility's operating budget. (Ref. 1-1)

PG&E recognizes the significant amount of energy used by the water treatment industry. This document was developed as one element in the utility's programs to provide information about the industry and to encourage incorporation of energy efficiency in the design and operation of water treatment facilities. Also, this document provides a basis for PG&E to offer a financial incentive to utilities that implement technology or equipment that exceed the energy efficiency of the 'baseline' or 'standard' technology or equipment.

Irrespective of the economic advantages of lowering their cost for electricity, it is understood that water treatment utilities have other objectives that must take precedence over energy savings. Those objectives include:

- Maintaining water quality
- Meeting the quantity of daily consumer demand
- Providing water supply in emergency situations such as fires and power outages

There are two primary sources of water for public drinking water supply, groundwater and surface water. In California, 30 million people (90% of the population) are served by public water supply facilities. Californians consume 6.1 billion gallons of water per day of which 2.8 billion gallons per day (BGD) are from groundwater and 3.3 BGD are from surface water sources.

Groundwater is withdrawn from subterranean aquifers. Surface water is withdrawn from a river, lake or an ocean. Both groundwater and surface water usually contain various physical, chemical and biological contaminants. Surface water usually contains more chemical and biological contaminants that need to be removed during treatment. The U.S. Environmental Protection Agency (EPA) has established an extensive array of regulations that apply to the treatment of drinking water. The regulations establish maximum allowable contaminant levels (MCL) of microorganisms, disinfectants, disinfectant by-products (DBP), inorganic chemicals, organic chemicals and radionuclides in drinking water. The regulations provide an alternative to meeting the MCL if specified treatment techniques (TT) are used. The regulations also require extensive monitoring of the source water and treated water and establish additional MCL or TT requirements that are phased-in over the next decade, depending on the source of the water and the number of people served by the treatment facility. For some contaminants, such as *Cryptosporidim,* watershed protection and pre-filtration are acceptable alternatives to use of advanced treatment such as ozone, ultraviolet radiation (UV) or chlorine dioxide.

Summary information about the EPA regulations is provided in Appendix A. In addition to the current federal regulations, the State of California has many regulations under development, many of which are related to the EPA regulations. A list of the California regulations that are under development is also provided in Appendix A.

People who work in the water treatment industry are vigorously engaged in understanding the new and pending regulations, as evidenced by the many recent webcasts sponsored by the American Water Works Association (AWWA) on this topic. An extensive amount of research is being conducted by people in the water treatment industry to assess the level of treatment provided by the various treatment methods, to assess the order (sequence) those treatment methods should be used and to estimate the cost of the treatment options. General information about current and pending regulations is provided in Section 2 of this study.

Currently, many treatment facilities that treat groundwater only provide disinfection. Typical TT for surface water includes screening, adding chemicals for flocculation, clarification, filtration and disinfection. Additional information about typical characteristics of groundwater and surface water and typical treatment processes for each is provided in Section 3. Section 4 provides more detailed information about the typical TT and advanced technologies for treating drinking water.

Seawater and brackish well water are emerging sources of water supply. Interest in desalination has increased in California since the passage of state laws that require proposed developments provide more certainty of adequate water supplies during the permit review process. However, seawater contains high levels of dissolved salts. Although the cost for desalination has been declining in recent years, the cost is still high when compared to the cost for treatment of other surface water. In addition, the concentrate produced by the desalination process has a high salt concentration. Due to the high salt concentration, the issue of how to dispose the concentrate has been another impediment to widespread use of desalination. The California Coastal Commission's 2004 report: Seawater Desalination and the California Coastal Act identifies 12 existing desalination facilities along the California coast. (Ref. 1-2) Of the 12 facilities, 4 are public facilities. One was inactive and one was used intermittently. The report also identified approximately 20 new facilities that were being considered, 12 of those facilities were for publicly owned facilities that were in the planning stage and 1 public facility that was in the design phase. Additional information about desalination technology is provided in Section 4.

Sections 5, 6, 7 and 8 address the following topics, respectively: results from a small survey on current utility treatment practices, strategies for compliance with the pending regulations, energy efficiency opportunities and conclusions from this study.

References:

1-1) *Energy Use at Wisconsin's Drinking Water Facilities*, Energy Center of Wisconsin, Report 222-1, July 2003.
1-2*) Seawater Desalination and the California Coastal Act*, California Coastal Commission, March 2004.

2. Current Regulations and Regulations Under Development

2.1 Overview

The EPA has established national primary drinking water standards that limit the levels of contaminants in drinking water. These regulations set maximum allowable contaminant level (MCL) or required treatment techniques (TT) for microorganisms, disinfectants, disinfectant by-products (DBP), inorganic chemicals, organic chemicals and radionuclides.

The EPA regulations require differing levels of treatment depending on the source of the water. Previously, EPA's surface water treatment rules required plants treating either surface water or groundwater under the direct influence of surface water to filter their water or meet criteria for avoiding filtration so that certain contaminants are controlled and to disinfect the water. However, groundwater (not under the direct influence of surface water) was not required to be filtered, but was required to be disinfected.

Two new regulations, the Stage 2 Long Term Enhanced Surface Water Treatment Rule (LT2), and the Stage 2 Disinfectants and Disinfection Byproduct Rule (DBP2), are focused on balancing the risk of disease from microorganisms with the risk of adverse health effects from DBPs. The most important classes of microbial contaminants are *Cryptosporidium*, Giardia, Legionella and Viruses. The most important DBPs are bromate, chlorite, haloacetic acids (HAA5) and total trihalomethanes (TTHMs).

2.2 Microorganisms

Cryptosporidium are microscopic parasites that cause diarrheal disease. Current regulations require filtering to reduce source water Cryptosporidium levels by 99 percent (2-log). New monitoring and regulations for *Cryptosporidium* are currently being implemented. These requirements are discussed in more detail in the section on the LT2 rule. Three TTs (ozone, chlorine dioxide and UV) are accepted by the EPA for meeting the control requirements.

Giardiasis is a diarrheal illness caused by a one-celled, microscopic parasite, Giardia lamblia. Current regulations require 99.9% (3-log) removal of Giardia. Giardia can be controlled by filtration, and long contact-time chlorine based disinfection.

Legionella is a bacterium causing a type of pneumonia. Legionella is transmitted by breathing in contaminated water vapor. No MCL limit is established, but EPA asserts that it will be effectively removed by disinfection sufficient to control Giardia and viruses.

Viruses are tiny particles containing DNA or RNA sometimes contained within a membrane. They are so small as to be invisible in ordinary light, and can only be seen with an electron microscope. Viruses multiply only in living cells and can cause disease. Conventional filtration will not remove viruses, but they are well controlled by most types of disinfection. Current regulations require 99.99% (4- log) removal of viruses.

Total Coliform Bacteria is used as an indicator that other potentially harmful bacteria may be present. Current regulations require that if 5% of samples test positive, additional testing for fecal coliforms and E-coli must be done. The presence of E-coli in these tests is an acute MCL violation.

Turbidity is an indication of the effectiveness of filtration. Current regulations require that turbidity never exceed 1 nephelometric turbidity units (NTU), and 95% of daily samples must not exceed 0.3 NTU.

2.3 Stage 2 Long Term Enhanced Surface Water Treatment Rule (LT2)

Cryptosporidium are microscopic parasites that cause diarrheal disease in animals and humans. Once an animal or person is infected, the parasite lives in the intestine and passes in the stool. The parasite is protected by an outer shell that allows it to survive outside the body for long periods of time and makes it very resistant to chlorine- based disinfectants. *Cryptosporidium* is a significant concern in drinking water because it contaminates most drinking water sources. During the past two decades, cryptosporidium has become recognized as one of the most common causes of waterborne disease in the United States. Consuming water with *Cryptosporidium* can cause gastrointestinal illness, which may be severe and sometimes fatal for people with weakened immune systems (including infants, the elderly, chemotherapy patients and people who have AIDS).

Current regulations require filtering to reduce source water *Cryptosporidium* levels by 99 percent (2-log). Recent data on *Cryptosporidium* indicate that this treatment is sufficient for most treatment plants, but additional treatment is necessary for certain higher risk plants. The higher risk plants include plants that filter the water but have high levels of *Cryptosporidium* in their source water and all plants that do not filter the water.

The LT2 rule requires all surface water plants serving over 10,000 people monitor their source water monthly for two years to measure: *Cryptosporidium*, E-coli, and Turbidity levels. The running annual averages of source water *Cryptosporidium* (oocyst/L) will be used to assign a treatment plant to one of four classifications or Bin Numbers as follows: Bin 1 less than 0.075/L, Bin 2 more than 0.075/L but less than 1.0/L, bin 3 more than 1.0 but less than 3.0/L and bin 4 more than 3.0/L.

Plants in Bin 1 that provide filtration (conventional, slow sand, diatomaceous earth or direct filtration) will not require additional *cryptosporidium* treatment.

Plants in Bin 2 that filter must provide an additional 1-log reduction, except for plants using direct filtration that requires a 1.5-log reduction. Bin 3 plants must provide an additional a 2-log reduction, and plants using direct filtration a 2.5-log reduction. Bin 4 plants must provide an additional 2.5 and 3.0-log reduction.

The LT2 rule provides a microbial tool box which allows plants to achieve specified levels of *Cryptosporidium* reduction by adding a watershed protection program, pre-filtration (riverbank filtration or pre-sedimentation), improved treatment (enhanced filtration, two-stage lime softening, etc.), alternative treatment (membranes, slow sand filtration), or inactivation (UV, chlorine dioxide or ozone). These options can be used alone or in combination to achieve the required *Cryptosporidium* reductions for Bins 2 through 4.

EPA data from the Information Collection Rule shows that the median oocyst levels in unfiltered water supplies is 0.0079 oocyst /liter, as opposed to the average for filtered water supplies of 0.052 oocyst /L. Since filtered water systems, in compliance with LT2, will achieve a 3-log reduction (99.9%), they will produce treated water with an average of 0.000052 oocyst /L. To achieve a similar level of *Cryptosporidium* in treated water; unfiltered plants with source water levels of 0.01 oocyst/L would require 3-log of inactivation. LT2 consequently requires all unfiltered water treatment plants to provide at least 2-log of inactivation and if the median source exceeds 0.01 oocyst/L, 3-log of inactivation is required. In addition the 2 or 3-log inactivation must be achieved using two or more disinfectants. Each disinfectant must achieve by itself the total inactivation of one of three target pathogens e.g. *Cryptosporidium* 2 or 3-log, Giardia 3-log and viruses 4-log.

The EPA recognizes three technologies (ozone, chlorine dioxide, and UV) for meeting the LT2 *Cryptosporidium* treatment requirements. The efficacy of any chemical disinfectant is dependent on the concentration (mg/L) and the contact time in minutes. The EPA has issued CT (mg/L x minutes) for various levels of *Cryptosporidium* inactivation as a function of source water temperature. To obtain a specific log reduction for either disinfectant the appropriate CT conditions must be documented. Although both ozone and chlorine dioxide can achieve 2-log reduction of *Cryptosporidium*, the contact times are long and for chlorine dioxide the required concentration may produce chlorite DBP values exceeding the MCL. UV on the other hand can easily achieve 2 or 3-log reductions and produces no DBP.

2.4 Disinfection By-Products (DBP)

During the disinfection process, organic and inorganic material in source waters combines with certain chemical disinfectants to form DBP. After years of study and analysis, the EPA has determined that the weight of evidence supports the conclusion that long-term exposure to DBP causes an increase in certain cancers, and may contribute to adverse reproductive consequences. Currently, chlorine is the most widely used disinfectant and it is one of the chemical disinfectants that forms DBPs.

Current DBP regulations set MCLs for Bromate at 0.010 mg/l, Chlorite at 1.0 mg/l, five Haloacetic acids (HAA5) at 0.60 mg/l and Total Trihalomethanes (TTHMs) at 0.80 mg/l.

2.5 Stage 2 Disinfectants and Disinfection Byproduct Rule (DBP 2)

EPA analysis of DBP data, submitted by drinking water plants under the Information Collection Rule, documents that elevated TTHM and HAA5 levels regularly occur at some locations in the distribution system while the overall average of TTHM or HAA5 levels at all DBP monitoring locations is below the MCL. The data from the Information Collection Rule revealed that the highest TTHM and HAA5 levels can occur at any monitoring site in the distribution system. In fact, the highest concentrations did not occur at the maximum residence time locations in more than 50% of all ICR samples. The fact that the locations with the highest DBP levels vary in different public water systems indicates current DBP monitoring may not accurately represent the high DBP concentrations that actually exist in distribution systems, and that additional monitoring is needed to identify distribution system locations with elevated DBP levels.

The DBP2 rule retains the current MCL for DBP, but adds a detailed monitoring plan to assess the levels of the regulated DBP at specific locations within the distribution system (systems who have 8 consecutive quarters of compliance samples below 40 mg/L TTHM and 30 mg/L HAA5 need not conduct the monitoring). The sampling points will be identified through an Initial Distribution System Evaluation (IDSE) using historic compliance data, system flow data, hydraulic modeling etc. The sample points will be monitored for two years, and Locational Running Annual Averages (LRAA) for TTHM and HAA5 reported. An LRAA exceeding either DBP limit triggers an Operational Evaluation and Report that examines the treatment plant operations and identifies changes to operations or treatment plant process modification to attain compliance. Modification to achieve compliance may be as simple as reducing water retention time, increased flushing etc. However, in some cases capital improvements may be needed such as enhanced filtration, changing disinfectant or use of other TT.

EPA’s analysis of the new treatment study data confirmed that certain technologies are effective at reducing DBP concentrations. The EPA identified granular activated carbon (GAC) and nanofiltration as Best Available Technologies (BAT) for DBP removal. Other studies found UV light to be highly effective for inactivating *Cryptosporidium* and Giardia at low doses without promoting the formation of DBP.

2.6 Inorganic Chemicals, Organic Chemicals and Radionuclides

The EPA has established MCL for many inorganic chemicals and organic chemicals and some radionuclides. Contaminants of particular concern to many water treatment plants include: arsenic, nitrates, herbicides and pesticides. The last three are particularly common in agricultural regions.

2.7 National Secondary Drinking Water Regulations

The EPA has also established National Secondary Drinking Water Regulations that set non-mandatory water quality standards for 15 contaminants. EPA does not enforce these "secondary maximum contaminant levels" or "SMCLs." They are established only as guidelines to assist public water systems in managing their drinking water for aesthetic considerations, such as taste, color and odor. These contaminants are not considered to present a risk to human health at the SMCL.

3. Water Systems

3.1 Typical Characteristics of Groundwater

Groundwater is water that comes from subterranean sources. Groundwater has usually percolated through many layers of soil, sand and/or rock. The water may come into contact with various organic and inorganic materials as it percolates through the ground. Although groundwater is typically clear and cold, it may contain the following and other contaminants:

Microorganisms
- Viruses
- Bacteria

Inorganic chemicals
- Arsenic
- Chloride
- Iron
- Nitrate
- Manganese
- Sulfate

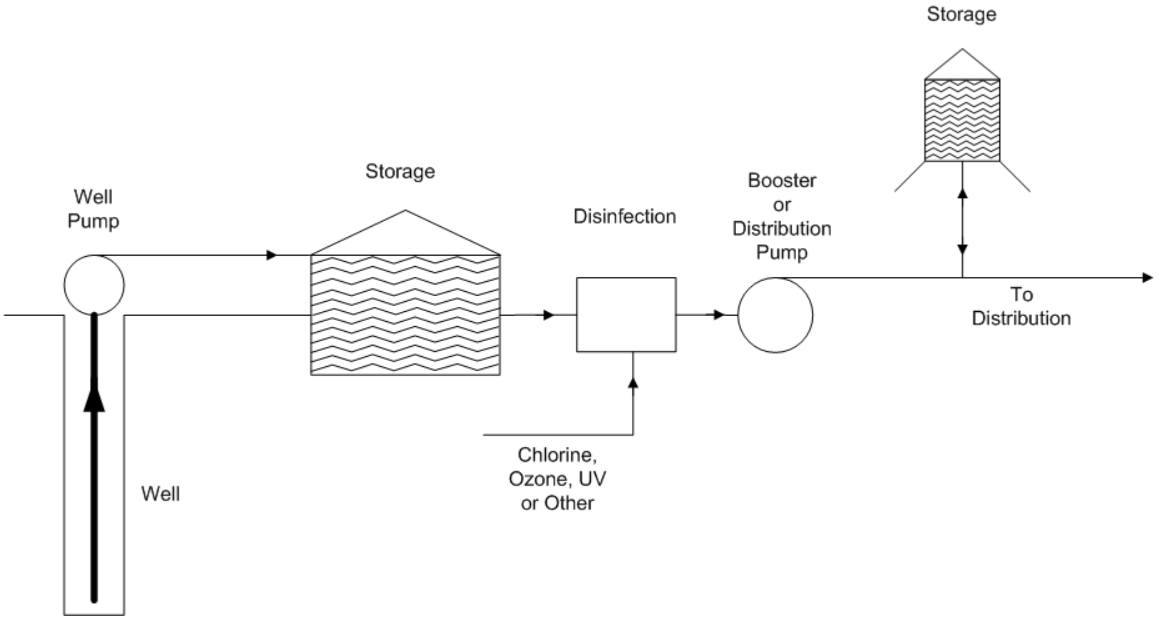
Organic chemicals
- Herbicides
- Pesticides
- Polychlorinated biphenyls (PCBs)

Radionuclides
Color
Odors
Gases

3.2 Typical Treatment for Groundwater

Often, groundwater is treated only by disinfection. Chlorine is commonly used for disinfection, however there are several other methods for providing disinfection. Section 4 provides detailed information about the other primary techniques used for disinfecting drinking water. Groundwater is required to be treated by additional processes if the concentration of any contaminant exceeds the limits established by regulatory agencies. Figure 3.1 is a schematic of a typical groundwater treatment system.

Figure 3.1. Schematic Diagram of a Typical Groundwater Treatment Plant.



3.3 Typical Characteristics of Surface Water

Surface water is water that comes from rivers and reservoirs. Surface water can contain a wide variety of constituents due to the wide range of features and conditions the raw water may contact. Snowmelt or rain ‘run-off’ can contain minerals, silt, plant matter, algae and various biological impurities. Surface water may contain:

Microorganisms
- Viruses
- Bacteria
- Giardia Lamblia
- *Cryptosporidium*

Inorganic chemicals
- Copper
- Lead
- Mercury
- Silver
- Other heavy metals

Organic chemicals
- Herbicides
- Pesticides
- Volatile organic compounds (VOCs)

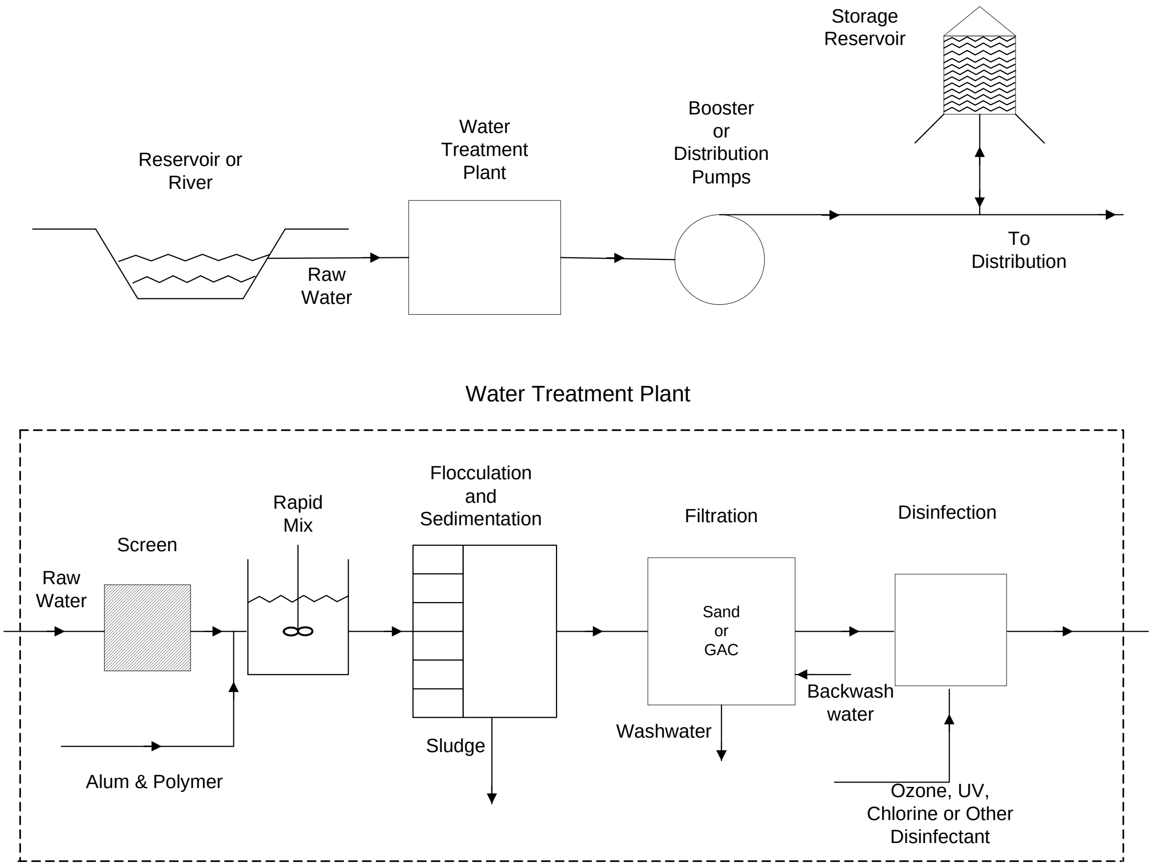
Color
Odor and tastes
Gases
Turbidity
Algae

Surface water quality can be affected by numerous factors such as weather conditions, disposal from upstream facilities, and urban and farm run-off.

3.4 Typical Treatment for Surface Water

Treatment plants that process surface water typically provide several processes in order to remove the broad range of pollutants that could be present in the water. Several physical processes are typically used in order to remove pollutants. Physical processes include screening, coagulation, flocculation, sedimentation and filtration. Like groundwater, surface water is disinfected prior to discharge in to the distribution system. Section 4 provides detailed information about processes used in surface water treatment plants and disinfection alternatives. Figure 3.2 is a schematic of a surface water treatment facility.

Figure 3.2. Schematic Diagram of a Typical Surface Water Treatment Facility



Reference:
Water and Wastewater Industries: Characteristics and Energy Management Opportunities, CR-106941, Electric Power Research Institute. Copyright 1996.

3.5 Electrical Consumption for Typical Groundwater and Surface Water Treatment Plants

The vast majority of electricity consumed in a typical facility treating groundwater that provides only chlorination for disinfection, is associated with pumping the water. The report, *Water and Wastewater Industries: Characteristics and Energy Management Opportunities* (Ref. 3-1) indicates that for a 'typical' plant producing 1 million gallons per day (MGD) of drinking water, approximately 600 kWh/day would be used for pumping water from a well, 10 kWh/day would be used chlorinating the water and 1,200 kWh/day would be used for booster (distribution) pumping. The treatment facility was assumed to have a lift of 150 ft from the groundwater table to the level of a storage tank and a distribution system pump with a discharge pressure of 125 PSI. For this facility, less than 1% of the electricity is used in the treatment process. Based on these criteria, the energy requirement for treatment is 10 kWh/million gallons (MG) of water produced. The energy requirement for the facility is 1,810 kWh/MG of water produced.

Table 3.1 shows the approximate electrical energy requirements for various treatment processes for plants ranging from 1 MGD to 100 MGD in size. Based on the information in the table, the processes utilize 5-10% of the total electrical energy consumption of a typical surface water treatment plant. Based on this information, the energy requirement for treatment ranges from 144 kWh/MG for the smaller plant to 78 kWh/MG for the larger plant. The energy requirement for the facility is 1,470 kWh/MG for the smaller facility and 1,404 kWh/MG for the larger plant.

Table 3.1. Electricity Requirement for 'Typical' Surface Water Treatment Plants

	Plant Size 1 MGD	**Plant Size 10 MGD**	**Plant Size 100 MGD**
Process	**Electrical Energy Consumption (kWh/d)**	**Electrical Energy Consumption (kWh/d)**	**Electrical Energy Consumption (kWh/d)**
Raw Water Pumping	121	1,205	12,055
Screening (1)	16	48	144
Alum Feed System	9	10	80
Polymer Feed System (1)	27	30	240
Rapid Mixing	41	308	3,080
Flocculation	10	90	904
Sedimentation	14	88	876
Sludge Pumping	4	40	400
Filter Backwash Pumps	8	77	767
Backwash Water Discharge	13	123	1,288
Chlorination	2	3	8
subtotal Treatment Only	144	817	7,787
Distribution Pumping	1,205	12,055	120,548
Total (kWh/day)	1,614	14,894	148,177

(1) Estimated electrical consumption

Water and Wastewater Industries: Characteristics and Energy Management Opportunities.
Electric Power Research Institute. CR-106941. Copyright 1996.

Table 3.2. Energy Consumption for Typical Water Treatment

Water Source	Small Plant 1-5 MGD Energy Consumption kWh/MG	Large Plant 100 MGD Energy Consumption kWh/MG
Groundwater	10	~10
Surface water	144	78

References:

3-1) *Water and Wastewater Industries: Characteristics and Energy Management Opportunities.* Electric Power Research Institute. CR-106941. Copyright 1996.

4. Treatment Techniques

4.1 Conventional Treatment Techniques for Surface Water Treatment Facilities

Screening

The purpose for screens is to remove leaves, sticks and other debris. Screen openings range in size from a fraction of an inch to more than an inch. Two sizes of screens can be used in facilities where larger debris is removed ahead of the smaller debris.

Rapid Mixing

The purpose of rapid mixing is to achieve broad dispersion of chemicals added to the raw water. The chemicals are designed to enhance the coagulation and flocculation of fine suspended particles that otherwise would not settle by gravity in the sedimentation tanks.

Coagulation

The raw water contains fine suspended particles with similar electrical charge that prevents them from agglomerating. In this stable solution, colloids and suspended solids are difficult to remove. The addition of a chemical reagent, or coagulant, destabilizes the colloid electrostatic charge and allows separate colloids to agglomerate.

Flocculation

High molecular weight chemicals are used to attract and trap the fine suspended particles. The high molecular weight chemicals form ‘long’ fibrous webs that trap the destabilized fine particles. The combination of the fibrous molecules plus the trapped, fine particles become heavy enough that they will ‘settle out’ of the water by gravity in the sedimentation tanks.

Sedimentation

Sedimentation is the process of utilizing gravity to remove suspended solids from the water. Sedimentation tanks are designed as large tanks in which the water is quiescent. The very slow movement of the water through the tank allows suspended solids to settle out of the flow, to the tank bottom. As discussed previously, alum and polymer are often added to enhance the settling of fine particles. Sedimentation is not a disinfection process, however it is a process that reduces the amount of disinfectant required. In addition, by removing most of the organic material from the water, less organic material remains in the water to form DBP when the disinfectant is added. Approximately 85% of the suspended matter entering the sedimentation tank is removed during the sedimentation process. The settled material is referred to as sludge or residual. The sludge is removed from the sedimentation tank with the use of scrapers that move the sludge to a sump from which the sludge is pumped out of the tank. The sludge may be dewatered by mechanical process, such as a filter press or may be dewatered by use of drying beds. The dewatered or dried sludge is then hauled off-site for disposal.

Granular Filtration

Granular filters are used to remove most of the remaining particles. There are four main types of granular filters: sand, dual media of sand and anthracite coal, diatomaceous earth and granular activated carbon (GAC).

Granular filter materials remove fine solids that pass through the sedimentation process. Sand filters trap solids whereas porous filter material such as GAC adsorb and absorb particulates. Adsorption refers to the adherence of particulates to the surface of the activated carbon, while absorption is the trapping of the particles in channels of the activated carbon. For the purposes of the granular filtration process, these aspects are not distinguished.

Granular filters need to be backwashed or if GAC, regenerated. Generally, filters are backwashed once every 24 to 48 hours, for a period of 15 to 20 minutes. The solids in the backwash water are typically concentrated and the sludge is mixed with the sludge from the sedimentation tank. The backwash water is re-directed back to the rapid mix area for treatment.

In addition to being effective in removing fine particulates, GAC also removes volatile and synthetic organic compounds, DBP, radionuclides in addition to chemicals that impart an unpleasant taste and odor. When the adsorption and absorption properties of the GAC are exhausted, the carbon must be regenerated or replaced. It is expensive to regenerate or replace GAC and the spent GAC may be classified as a hazardous waste.

Disinfection

Disinfection refers to destroying disease-causing organisms or rendering them unable to replicate. Consequently, disinfection does not result in all organisms being destroyed, as is the case of sterilization. Disinfection in the water treatment industry is achieved by using chemical agents and/or physical agents. The most common chemical agents include chlorine, chlorine dioxide, ozone and hydrogen peroxide. The main physical agent for disinfecting drinking water is ultraviolet radiation (UV). The efficacy, advantages and disadvantages of these disinfectants are discussed later in this section.

4.2 Other Treatment Techniques

Aeration

A common treatment process is aeration, dramatically increasing the surface area of air and water contact. Aeration increases the concentration of oxygen in the water and improves the quality of the water in several aspects. Aeration releases gases, such as methane, ammonia and hydrogen sulfide trapped in the water. Aeration is helpful for removing volatile organic compounds. Also, aeration enhances the removal of iron, manganese, zinc and other metals by oxidizing the metal and forming precipitates that can be removed during sedimentation. Removal of unwanted gases and metals reduces objectionable taste and odor.

Aeration can be accomplished in several ways, broadly separated into two categories. The first category is subsurface introduction of air; the second category is mechanical systems. Subsurface aeration systems range from systems with fine bubble diffusers, to coarse bubble diffusers, to aspirators. Generally, fine bubble aeration systems provide greater oxygen transfer than coarse bubble aeration systems. However, coarse bubble or aspirated systems would provide greater removal of volatile organic compounds than fine bubble aeration systems. An example of a mechanical aeration system is spray aeration. Spray aeration systems spray the water into air. As the water is broken into small droplets, a large water-to-air surface area is created. Other mechanical methods of aeration are to cascade water through trays or over waterfalls.

In general, a fine bubble aeration system is more energy efficient than a coarse bubble aeration system or a mechanical aeration system for the purpose of improving dissolved oxygen concentration. However, a mechanical aeration system may be more efficient for removal of volatile organic compounds than a fine bubble aeration system or coarse bubble aeration system. Thus, it is crucial to understand the specific objectives of the treatment process at each treatment facility when identifying opportunities for improving energy efficiency.

Pretreatment Oxidation

Pretreatment oxidation involves the use of an oxidant or disinfectant early in the treatment process, such as after the screening process. Considerations for this process are:

- Oxidize compounds for subsequent removal
- Control growth of microorganisms and higher organisms that could detrimentally affect downstream processes

- Provide initial treatment with sufficient time for further treatment if necessary

There are potential problems associated with pretreatment oxidation:
- Variable water quality could result in the use of large amounts of the oxidant
- Depending upon the oxidant, DBP could be formed (particularly if chlorine is used)
- Oxidant can lose some cells creating objectionable tastes or odors

The advantages and disadvantages associated with typical oxidants will be discussed in Section 4.3 Disinfection Techniques.

Membrane Filtration

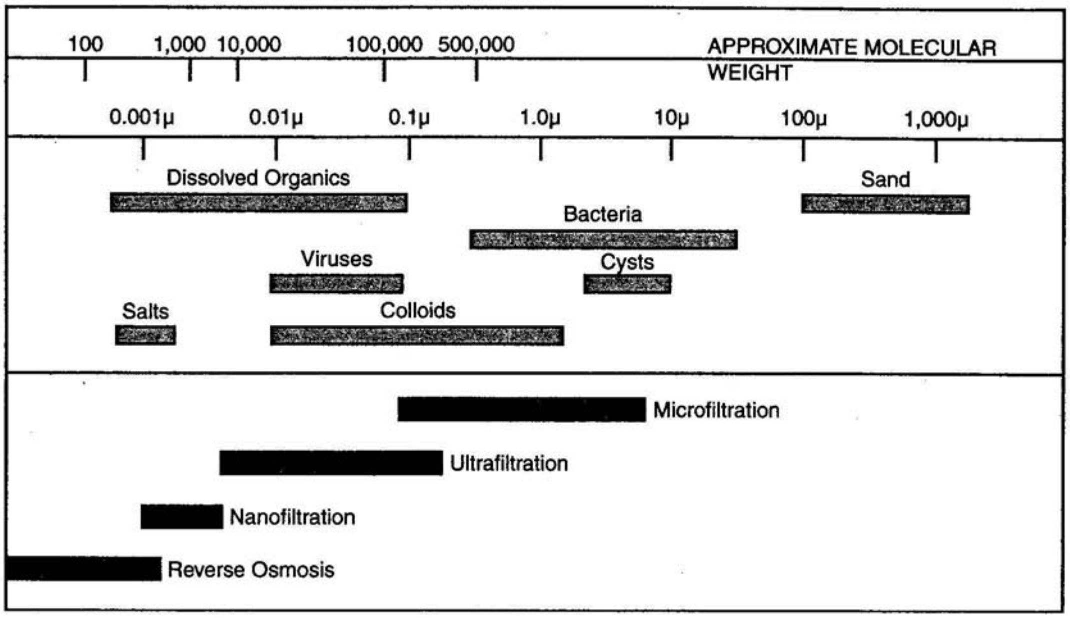
Membrane filtration can be used to remove a broad range of contaminants from particles as large as sand and as small as dissolved organics. There are four levels of membrane filtration applicable to water treatment: micro-filtration (MF), ultra-filtration (UF), nano-filtration (NF) and reverse osmosis (RO). Figure 4.1 shows the relative sizes of matter that are removed by each of the four levels of membrane filtration.

The 2005 EPA report *Low-Pressure Membrane Filtration for Pathogen Removal* reported there were 28 facilities in California using MF or UF for treatment of drinking water. (Ref. 4-1) The number of facilities planning to use either MF or UF has been growing dramatically over the last decade. There are several reasons for the growth in use of membrane processes:
- Surface Water Treatment Rule (SWTR) and subsequent revisions require higher levels of turbidity and particle removal. MF and UF processes can be used to consistently achieve treatment objectives.
- LT2 has identified membrane filtration as a separate TT that can be used as part of a “toolbox” of treatment options to obtain higher levels of *Cryptosporidium* removal.
- MF and UF are particulate filters and can replace conventional granular filter systems.
- MF and UF processes are flexible- they can be used in conjunction with other treatment processes and quality of the filtrate is not affected by process chemistry or variation in flow.
- Capital cost for MF and UF processes is nearly competitive with conventional alternatives.
- Membrane filtration can provide space savings when compared to conventional alternatives.

An important distinction between granular filtration and membrane filtration is that unlike granular filtration, the pore size in membrane filtration is very uniform. Because of that uniformity, membrane filters remove a targeted particle size or microorganism with a very high level of confidence.

The trans-membrane pressure (TMP) is the difference in pressure from the feed water to the filtrate across a membrane. The TMP for MF and UF processes can range from 4 – 30 PSI for MF processes and from 4 – 40 PSI for UF processes. The smaller the pore size of the membrane, the greater the hydraulic pressure must be in order to provide the driving force for the filtration process. Although recent developments in technology have reduced the pressure needed when using NF and RO, still, relatively high pressures are needed for those processes and these filtration techniques have substantially greater cost.

Figure 4.1. Mass Transport in Membrane Filtration



Micro-filtration and Ultra-filtration Membranes for Drinking Water, American Water Works Association, M53, Manual of Water Supply Practices. Copyright 2005.

Desalination

Seawater is considered to be surface water and if treated to be drinking water, it must comply with the regulations for treatment of surface waters. Desalination is a process that removes dissolved minerals from seawater or brackish water. Other impurities are also removed by desalination technologies. The five major technologies for desalinating water are: reverse osmosis (RO), distillation, electro-dialysis, ion exchange and vacuum freezing. RO and distillation are the primary technologies being considered by municipalities, water districts and private companies in California.

Desalination by distillation requires the intake water to be heated to produce a vapor, which is then condensed to produce water with a low concentration of dissolved salt and other minerals. The most common methods of distillation include multistage flash, multiple effect distillation and vapor compression.

Advantages of Distillation plants:

- Require less pretreatment of feed water than is necessary for reverse osmosis.
- Use feedwater of lower quality than reverse osmosis.

Disadvantages of Distillation plants:

- Extremely energy intensive
- Maintenance of evaporator components to corrosive feedwater

Co-location of desalination facilities with power production facilities has advantages and disadvantages. Additional information on this topic is available in the California Coastal Commission Report: *Seawater Desalination and the California Coastal Act*, March 2004.

Desalination by reverse osmosis involves pumping feedwater at high pressure (800-1000 PSI) through a semi-permeable membrane. The pores of the membrane are large enough to allow water molecules to pass through, yet are too small to allow the passage of salts, minerals and microorganisms. Reverse osmosis facilities generally involve four processes: pretreatment, pressurization, membrane separation and disinfection. Chemical and physical processes such as coagulation, sedimentation and filtration can be used to provide pretreatment. Pretreatment may also be accomplished by use of ultra-filtration.

Advantages of Reverse Osmosis:
- Less energy is required.
- Discharge has less thermal impacts.
- Fewer corrosion problems.
- Higher recovery rates.
- Smaller land area requirement.

Disadvantages of Reverse Osmosis:
- Greater sensitivity to poor water quality, causing more frequent shutdowns.
- Pretreatment with the use of biocides, coagulants and other chemicals is usually required.
- More frequent cleaning and maintenance is usually required, often using chemicals and cleaning agents.
- Membrane fouling and maintenance can result in high maintenance costs.

Methods for recovering energy from both the distillation and the reverse osmosis processes have been developed. However, both processes are still very energy intensive. The California Coastal Commission report referred to above is a good source of additional information on seawater desalination.

Ion Exchange
An ion is an atom or molecule that has gained or lost one (or more electrons). Ion exchange is a chemical reaction wherein an ion from solution is exchanged for a similarly charged ion attached to an immobile solid particle. For example, a calcium ion (Ca^{+2}) in water could be exchanged for 2 hydrogen ions ($2H^{+}$) that had been attached to an immobile solid particle. The immobile solid particle can be either a naturally occurring material called a ‘zeolite’ or synthetically produced material called a ‘resin’. The synthetic resins are the predominant material used today because their characteristics can be tailored for removal of specific contaminants. Ion exchange processes can be designed to remove either positively charged ions, such as calcium ions or magnesium ions, or negatively charged ions. The ion exchange process is very effective for reducing ‘hardness’ (removing iron, calcium and/or manganese).

The ion exchange process is a reversible chemical reaction. As a resin exchanges more of its ions for removal of the contaminant, the resin gradually loses its effectiveness. The resin can be regenerated by passing a concentrated brine solution through the resin, causing the above process to be reversed. However, due to the elevated salt concentration, disposing of the brine solution can be problematic. Due to this issue and the cost for ion exchange systems, currently, there are few plants that utilize ion exchange technology. Ion exchange is frequently used in industrial processes when very pure water is required.

4.3 Disinfection Techniques

4.3.1 Chlorine Gas

Through most of the 1990’s chlorine gas was used for disinfection at the majority of all community surface water and groundwater systems in the U.S. The majority of chlorine produced in the U.S. is manufactured from the electrolysis of salt brine and caustic solutions. Chlorine gas can also be produced by oxidation of hydrochloric and by the reaction of sodium chloride and nitric acid. Since chlorine is a stable compound, it is usually produced by a chemical manufacturer. Chlorine gas is normally compressed into a liquid for delivery and storage in one-ton cylinders, tanker truck or railcar. (Ref. 4-2)

A chlorinator, consisting of a pressure regulator, feed rate indicator and control, and an injector is used to meter and control the rate at which chlorine is added to the water. Although liquefied chlorine gas is the least expensive source of chlorine, the capital cost for a gas chlorination system is moderately priced compared to the cost for other chlorine-based disinfection techniques.

Chlorine is an oxidant and kills bacteria by penetrating their cell walls and disrupting their metabolism. However, chlorine is not as effective against *Cryptosporidium* and Giardia lamblia cysts as other disinfectants, such as ozone. A longer contact time and higher concentration of chlorine can improve the disinfection performance of chlorine against both of these organisms.

Due to its toxic properties, there has been increasing concern by water treatment agencies and the public about transporting chlorine through and storing it in urban areas. Santa Clara County, for example, has local regulations that prohibit the transportation and storage of chlorine in the county.

Chlorine can combine with organic and inorganic material in the water to form disinfection DBP. Trihalomethanes (THMs) and Haloacetic acids (HAA5) are commonly found in water that has been chlorinated. After years of study and analysis, the EPA has determined that the weight of evidence supports the conclusion that long-term exposure to DBP causes an increase in certain cancers, and may contribute to adverse reproductive consequences.

Advantages/Attributes of Chlorine are that it:

- Effectively inactivates a wide range of pathogens commonly found in water
- Leaves residual disinfectant in the water that is effective in the distribution system
- It is the least costly source of chlorine disinfectant on the basis of pounds of available chlorine
- Is a pure substance, and no other chemicals are added.
- Is easy to control and apply.
- Is beneficial for taste and odor control if not used in excess

Disadvantages of Chlorine are that it:

- Reacts with many naturally occurring organic and inorganic compounds in water to produce DBP.
- Exposure to chlorine gas is extremely hazardous and can result in acute inflammation of the upper and lower respiratory tract and can be fatal. (Medical statistics report 5-years cumulative data report the following approximate information: 27,800 exposures; 21,400 categorized as follows: 2,100 no effect; 17,000 minor; 2,100 moderate; 40 major; and 3 fatalities) (Ref. 4-3)
- Transport and storage of chlorine presents public health risk of accidental or intentional release of the gas and subsequent injury to those exposed.

4.3.2 Chlorine Dioxide

Chlorine dioxide is another chlorine-based disinfectant. Chlorine dioxide is a strong oxidant that can be used as a pretreatment oxidant to control tastes and odor, to control iron and manganese concentrations by forming a precipitate that can be removed by filtration, and as a disinfectant. Chlorine dioxide does not chlorinate.

Chlorine dioxide is a gas at standard temperatures and pressure. Because chlorine dioxide is explosive under pressure, it cannot be compressed and is never shipped. Chlorine dioxide is, therefore, generated onsite. There are several different processes for the production of chlorine dioxide, however the high cost of the generating equipment and the complexity of the process for producing chlorine dioxide are negative factors when evaluating disinfection options.

Chlorine dioxide is a strong oxidant and disinfectant, although its disinfectant mechanism is not well understood. Studies focus on two mechanisms: chemical reactions between chlorine dioxide and cellular matter and chlorine dioxide alteration of cell wall permeability. Chlorine dioxide is a more effective disinfectant than chlorine but is less effective than ozone. (Ref. 4-4)

In general, chlorine dioxide produces few DBP. Studies have shown that THM are not found after application of chlorine dioxide. However, chlorite, chlorate and organic DBP are formed from the use of chlorine dioxide. In particular, bromate is formed in water that contains bromide, which is often present in groundwater.

Advantages of Chlorine Dioxide are that it:
- It is more effective than chlorine and chloramines for inactivation of viruses, *Cryptosporidium* and Giardia.
- It oxidizes iron, manganese and sulfides
- It controls taste and odors resulting from algae and decaying vegetation and phenolic compounds.
- Halogen-substituted DBP not formed under proper generation conditions.
- Provides residual disinfectant in the collection system.

Disadvantages of Chlorine Dioxide are that it:
- Cannot be compressed, so it must be generated on-site.
- Chlorite and chlorate are formed as by-products of chlorine dioxide production.
- Generator efficiency and difficulty in optimization production can cause excess chlorine to be fed at the application point, which can result in halogen-substitute DBP formation.
- The cost for sodium chlorite is high.
- Cost associated with training, sampling and laboratory testing for chlorite and chlorate are high.
- There is limited information chlorine dioxide may damage developing fetuses. Water systems that use chlorine dioxide are required to conduct a rigorous monitor program of the concentration of chlorine dioxide at the entrance to the distribution system. Public notification is required if the chlorine dioxide concentration exceeds certain levels.

4.3.3 Sodium Hypochlorite

Sodium hypochlorite (NaOCl) is a salt of hypochlorous acid, HClO. Sodium hypochlorite is a colorless, transparent liquid made by dissolving chlorine gas in cold sodium hydroxide solution. Household bleach is a solution of sodium hypochlorite, usually a 3 – 6% solution. Typically, a 12% solution of sodium hypochlorite is purchased when it is used as a disinfectant at water treatment plants. Hypochlorous acid (HClO) is formed in equilibrium with the hypochlorite anion (OCl^-). Hypochlorous acid is a strong oxidant and can diffuse through the cell walls of bacteria. The acid inactivates enzymes essential to the digestion process and effectively destroys the microorganism’s ability to function.

A major advantage of sodium hypochlorite, like chlorine gas, is that it is easy to manage and is relatively inexpensive. Injecting the proper amount of sodium hypochlorite for disinfection is a relatively easy and straightforward procedure. Transport and storage of sodium hypochlorite is relatively safe however, the oxidation reactions are corrosive and contact with the sodium hypochlorite can cause burns.

Advantages of Sodium Hypochlorite are that it:
- It can be transported
- Is effective in disinfecting bacteria, viruses and fungi.
- Dosage is easily controlled.
- Produces a residual disinfectant.

Disadvantages of Sodium Hypochlorite are that it:
- Forms THM and HAA5.
- Is corrosive.
- Does not deactivate *Cryptosporidium* or Giardia Lambia.
- Losses strength if exposed to air.

4.3.4 Chloramination

Chloramines are formed by the reaction of ammonia with aqueous chlorine. Monochloramines, dichloramines and trichloramines are all formed by that reaction however; the goal is to maximize the formation of monochloramines. Monochloramine is a relatively weak disinfectant, hence it is not recommended for use as a primary disinfectant. However, monochloramine is relatively stable and is longer lasting than either chlorine or chlorine dioxide. Thus, chloranimation can be used for secondary disinfection against microbial growth in the distribution system.

There has been limited investigation of the mechanism by which chloramines inactivate microorganisms. Chloramines are thought to inhibit the respiration of bacteria. The mechanism of viral inactivation may be dependent on the type of virus and disinfectant concentration.

Special safety provisions are needed in the design of the storage and metering facilities to ensure adequate ventilation and safe handling of both ammonia and chlorine.

Chloramination was used at a water treatment facility (Ann Arbor, Michigan) that had subsequent treatment by granular activated carbon. Ammonia input to the filters provided a nutrient source that supported the growth of nitrifying bacteria. Nitrites rapidly reduce free chlorine, which then accelerates the decomposition of chloramines. This process reduces the disinfectant effectiveness of the chloranimation process.

Advantages of Chloranimation are that:

- Chloramines are not as reactive with organic material as free chlorine and thus produce fewer DBP.
- Monochloramine residual is more stable and longer lasting than free chlorine.
- Chloramine is inexpensive to produce.

Disadvantages of Chloranimation are that:

- Its disinfecting properties are weaker than chlorine, ozone and chlorine dioxide.
- Chloramines cannot oxidize iron, manganese or sulfides.
- Excess ammonia may lead to nitrification problems.

4.3.5 Ultraviolet Radiation

Ultraviolet radiation (UV) is light energy ranging from 100 to 400nm in wavelength, between the X-ray portion of the spectrum and the visible light portion. In most UV disinfection applications, the short wave portion of the UV spectrum is used. This section is referred to as UV-C and spans from 200 to 280nm.

Generation

UV is generated by electrons flowing through ionized mercury vapor in a lamp enclosed in a quartz sleeve. The lamp is separated from the water by the sleeve to maintain the optimum lamp operating temperature of approximately 40^{o}C. There are three common types of UV lamps: low pressure lamps, low-pressure high intensity lamps, and medium pressure lamps.

Low-pressure lamps are more efficient in converting electrical energy to germicidal UV light, but total output is much weaker than from a medium pressure lamp. Low-pressure lamps are most effective in smaller scale plants, typically 0.5 MGD or less.

Low-pressure high intensity (LPHI) lamps produce higher intensity UV and operate at lower pressure. They are effective for most sizes of plants.

Medium pressure (MP) lamps emit energy at much higher intensity than low-pressure lamps, and over a wider wavelength (180 to 1370 nm).

UV lamps are driven by ballasts that transform and control the power to the lamps. The ballasts produce heat and often must be cooled to avoid premature failure by overheating.

Low-pressure lamps emit essentially monochromatic light at a wavelength of 253.7 nm. Medium-pressure lamps are often used in large facilities. They have approximately 15 to 20 times the germicidal UV intensity of low-pressure lamps. The medium-pressure lamp disinfects faster and has greater penetration capability because of its higher intensity. However, these lamps operate at higher temperatures with significantly higher energy consumption. Low-pressure UV systems are generally 40 to 50% more energy efficient than medium pressure systems, but the large number of low-pressure lamps required may result in higher maintenance and capital costs.

Point of Application

UV systems are usually installed in the water treatment train after clarification and filtration but prior to the addition of a residual disinfectant. However, when UV is part of disinfection system utilizing advanced oxidation processes (UV/ozone or UV/peroxide) the UV system may be installed in other locations.

Reactor

Early installations of UV lamps for disinfection of water were installed in open channels. Currently most new installations are closed vessel disinfection systems. The reasons for this are:

- Smaller footprint
- Minimal pollution from airborne material
- Reduced staff exposure risk
- Modular design
- Better mixing/more uniform exposure of the water

UV reactors are designed to achieve plug flow, with a degree of radial mixing, and sufficient residence time to assure the required UV exposure is achieved throughout the reactor volume. Sensors are installed in the reactor to measure the amount of UV delivered to the water. These sensors provide real time monitoring of the UV intensity.

Inactivation/Disinfection Efficacy

UV light disinfects by photo-chemically altering an organism’s DNA preventing reproduction. Cells that cannot replicate cannot cause infection. This process is referred to as inactivation. The extent of inactivation is proportional to the UV dose. UV dose in (mj/cm^2) is defined as the UV intensity (mWatt-sec/cm^2) times the exposure duration in seconds. Research by the EPA, and American Water Works Research Foundation (AWWARF) have established that a UV dose of 40 mj/cm ^{2} will provide 3-log inactivation of bacteria, Giardia and *Cryptosporidium* with adequate safety factors. Viruses require significantly higher doses for inactivation (40-180 mW-sec/cm^2), but are very sensitive to chlorine disinfection, which is why UV disinfection is recommended for so called multiple barrier installations, where UV disinfection is paired with a low dose of chlorine or chloramines to inactivate viruses.

AWWARF reports “Ultraviolet radiation, in cost-effective doses, effectively inactivates common pathogens such as *Cryptosporidium*, Giardia and most bacterial pathogens. UV radiation, at drinking water treatment doses, does not create significant levels of DBP. These factors make UV treatment an attractive option for utilities seeking to control pathogens in both ground and surface waters.” The EPA lists UV in the LT2 as one of three methods to achieve the required 2-log inactivation of *Cryptosporidium*.

The City of New York is currently installing UV for disinfection of its unfiltered water supply. When completed it will be the largest UV facility in the world.

Advantages of UV:

- Does not form DBP
- Extremely effective for inactivation of Giardia and *Cryptosporidium*
- UV does not alter taste, odor, color or pH of the water
- Does not add any chemicals to the water
- Modular design-easy to expand and retrofit

Disadvantages of UV

- Does not produce a residual disinfectant
- Higher capital and operating costs than chlorine
- Limited applications in large capacity systems
- Possible exposure of staff to UV
- May require stand-by generation
- Ineffective in water that has high turbidity

4.3.6 Hydrogen Peroxide Treatment Technique

Hydrogen peroxide (H_2O_2) is a strong oxidizing agent, used extensively as a disinfectant in the medical, pharmaceutical, food and ultra-pure water industries. It is supplied commercially as a 30 to 70% solution in water. It is unstable during storage and decomposes slowly to water and oxygen. It is considered a hazardous chemical due to its strong oxidizing capabilities and can cause fires when it comes into contact with combustible materials.

In the 1950's, hydrogen peroxide was first used for drinking water disinfection in Eastern Europe, and in a few small-scale water systems in the US. It does not form chlorinated DBP, but its low stability necessitates it be used in conjunction with another disinfectant to provide a residual.
Compared to chlorine, ozone, chlorine dioxide, or UV, hydrogen peroxide is a rather poor disinfectant and is not approved as a stand-alone treatment for microbial control in water systems. However, hydrogen peroxide can be used to improve the performance of certain other disinfection methods (e.g., ozonation and UV), where hydrogen peroxide enhances the generation of hydroxyl radical oxidation of trace impurities. It is also used in combination with acetic acid to form peracetic acid, which is used by a few water treatment plants for primary disinfection.

4.3.7 Ozonation

Ozone was discovered in the late 1700's, but was not produced in quantity until the 1850's when Siemens invented the first ozone generator. It was soon discovered that ozone had germicidal properties, and its use as a water disinfectant evolved. The first commercial use of ozone as a drinking water disinfectant was at a French plant in 1906, which operated until 1970. The success of this plant resulted in the widespread use of ozone for drinking water disinfection in France and Europe.

In the past, ozone has been used in the US primarily for control of taste and odor, removal of iron and other water treatment needs, but has not been used as widely as in Europe for primary disinfection. The use of ozone as an oxidant/disinfectant has increased significantly in the US over the past decade. This is largely the result of concerns over the formation of halogenated DBP and the need to control *Cryptosporidium*. In both of these areas, ozone provides superior performance when compared to chlorine. There are now well over 300 ozone water treatment plants operating in the US. In the 1990's the Los Angles Dept. of Water and Power installed a 7,900-lb/day ozone plant, using on-site cryogenic oxygen production, to treat 600 MGD as a pre-oxidant for disinfection and microfloculation. This plant remains one of the largest ozone generation facilities in the world.

Ozone (O_3) is an allotropic form of oxygen that is unstable. It has a low solubility in water, and rapidly decomposes to oxygen in water containing organic impurities, but more slowly in purer water. The reported half-life of ozone in tap water at 20^oC is about 20 minutes. Ozone is one of the strongest chemical disinfectants in commercial use, and is over 50% higher in oxidative capacity than chlorine. As a disinfectant, ozone does not produce THM or HAA, however it does produce aldehides and in source waters containing bromine, ozone can produce bromate, a regulated DBP. Bromate production can be somewhat controlled by lowering the ph of the treated water, but ozone is not suitable for disinfection of source waters with high bromide content. Ozone has a high germicidal effectiveness against a wide range of pathogenic organisms including bacteria, protozoa and viruses. Ozone is one of the few disinfectants effective in controlling *Cryptosporidium*.

Ozone is toxic and the EPA has set an 8-hour exposure limit in air of 0.1 PPM. Fortunately, ozone has a pungent odor that is discernible well below the exposure limit.

The unstable nature of ozone requires that it be generated on site. Ozone is produced by passing dry air or pure oxygen through a corona discharge reactor. This reactor is a bundle of dielectric coated, glass tubes inside stainless steel tubes, subjected to an electrical field with a high potential voltage difference (10,000-20,000 volts) sufficient to generate a corona discharge. Because ozone production decreases as the gas temperature increases, a cooling system must be provided for optimum temperature control. Most large water treatment plants generate ozone from pure oxygen, as it produces higher concentrations of ozone making it more effective as a disinfectant. Ozone generation from pure oxygen also uses less on-site electricity per pound of ozone produced.

Because ozone decomposes easily, it must be injected into the water to be treated as quickly as possible. Ozone is expensive and its low solubility in water requires an efficient water/ozone contacting technique. Bubble diffusers are the most common method, however venturi injectors are also used, particularly if the water contains iron or other contaminants that when oxidized form solids that can plug bubble diffusers. Ozone transfer efficiencies range from 85% to 98% for bubble diffusers and about 70% for injectors.

Ozone in the exhaust gas from the ozone contacting process must be destroyed prior to venting. There are several destruction processes including catalytic and thermal based equipment.

Ozone is usually injected into the raw water stream after sedimentation and prior to filtration as a pre-oxidant. This provides primary disinfection, controls taste and odor, and precipitates iron, manganese and sulfide for subsequent removal during filtration. Pre-oxidation using ozone also breaks down organic contaminants into more easily biodegradable compounds that can be removed through biologically active filtration (slow sand filters, GAC etc.). The removal of these reactive organic compounds significantly reduces the formation of chlorinated DBP when chlorine or chloramine disinfectants are used to provide additional disinfection or as a residual disinfectant.

The efficacy of chemical disinfectants is measured by the concentration of the disinfectant in mg/L times the contact time in minutes. This factor is referred to as the “CT” value. Tables of CT values for microbial contaminants have been developed by the EPA for specific log reductions as a function of treated water temperature. For example, the EPA requires a CT value for ozone of 7.8 for a 2-log inactivation of *Cryptosporidium* at a water temperature of 20^oC. Assuming an ozone residual of 2.0 mg/L, an ozone contact time of 4 minutes would meet their requirements for a 2-log inactivation credit. This is significantly shorter time than is required by chlorine dioxide, the only other chemical disinfectant approved by the EPA for *Cryptosporidium* inactivation.

Advantages:

- Ozone is more effective than chlorine, chloramines, and chlorine dioxide for inactivation of viruses, *Cryptosporidium*, and *Giardia*.
- Ozone oxidizes iron, manganese, and sulfides.
- Ozone can sometimes enhance the clarification process and turbidity removal.
- Ozone controls color, taste, and odors.
- One of the most efficient chemical disinfectants, ozone requires a very short contact time.
- In the absence of bromide, halogenated DBP are not formed.
- Upon decomposition, the only residual is dissolved oxygen.
- Biocidal activity is not influenced by pH.

Disadvantages

- DBP are formed, particularly bromate when bromine is in the source water.
- The capital and operating cost of ozone generation is high.
- Ozone is unstable and must be generated on-site.
- Ozone is highly corrosive and toxic.
- Biologically active filters are needed for removing assimilable organic carbon and biodegradable DBP.
- Ozone decays rapidly at high pH and warm temperatures.
- Ozone provides no residual.
- Ozone production facilities require a higher level of operator and maintenance skill.

4.3.8 Ozone/UV

The UV irradiation of ozone is another advanced oxidation process. When dissolved ozone is irradiated it is converted to hydrogen peroxide, which then reacts with additional ozone to form hydroxyl radicals. It would thus seem that the process is essentially the same as hydrogen peroxide, except that UV irradiation is more costly and energy intensive than simply adding a solution of hydrogen peroxide to the ozone contactor.

One application where ozone/UV could be attractive is for compliance with the LT2 rule that requires unfiltered plants to install two different disinfection processes. Each disinfectant must achieve by itself the total inactivation of one of three target pathogens e.g. *Cryptosporidium* 2 or 3-log, Giardia 3-log and viruses 4-log. Ozone and UV are capable of meeting that criterion, and the hydroxyl radicals formed by UV irradiation of ozone should reduce the precursors that lead to DBP formed by a chlorine based residual disinfectant. Recent AWWARF research and field trials have shown that:

- Ozone alone was not effective for inactivation of *Cryptosporidium* at low water temperatures.
- Medium pressure UV light, either with or without ozone, was capable of cost-effectively meeting inactivation requirements for Giardia and *Cryptosporidium* at low temperatures.
- The use of ozone, MP-UV, and chlorine resulted in lower levels of halogenated DBP than the use of UV and chlorine alone.
- The use of ozone and MP-UV increased ultraviolet transmittance, which would result in lower capital and operating costs for new UV systems.
- Tests with unfiltered water revealed no difference in the re-growth potential between water disinfected with ozone followed by MP-UV and water disinfected with MP-UV alone.

This research study found that combining the strengths of ozone (oxidation, taste and odor reduction, and virus inactivation) and UV (inactivation of *Cryptosporidium*) can result in a cost-effective treatment strategy for a broad range of large surface waters, both filtered and unfiltered. By combining the two methods of disinfection, each can be optimized, maximizing the benefits of both technologies. Ozonation and UV light together can satisfy the need for both oxidation and inactivation while resulting in very low formation of regulated DBP at relatively low operating costs. Systems that already use ozone benefit from the increase in UV transmittance and the ability to operate smaller and more energy efficient equipment.

4.3.9 UV/Hydrogen Peroxide

UV irradiation of hydrogen peroxide (also an advanced oxidation process) may have some advantages compared to UV/ozone of hydrogen peroxide. First, the UV can meet all the LT2 disinfection criteria. Second, the cost (both capital and operating) should be considerably less than any process using ozone. Finally, the hydroxyl radical formation by adding a solution of peroxide to a segment of the UV train would be expected to reduce DBP precursors. AWWARF research on UV/hydrogen peroxide concluded that "The performance of the UV-H_2O_2 process when compared to ozonation was very encouraging and suggested that benefits similar to ozonation for TOC and DBP precursor control could be obtained using less complicated technology. The UV-H_2O_2 process may be especially attractive for small systems. An additional benefit of the UV-H_2O_2 process relative to ozonation is the absence of bromate formation in bromide-containing waters."

Furthermore the UV/hydrogen peroxide process has recently been installed for disinfection at a Dutch water treatment plant. "In its drinking water facility in Andijk PWN Waterleidingbedrijf Noord-Holland applies a new, innovative water treatment process. The process combines UV light and hydrogen peroxide to produce reliable drinking water from surface water. This is the first UV-peroxide facility on this scale. Since this technology is interesting for all water treatment facilities using surface water for drinking water production, it is of great interest worldwide. PWN is the first drinking water treatment facility successfully applying the UV-peroxide technology on a large scale." PWN developed this technology in collaboration with the Canadian supplier of the UV equipment.

UV/hydrogen peroxide treatment is based on the combined use of UV light and hydrogen peroxide. It is a cost-effective method, since two treatment steps are integrated: disinfection and degradation of organic contaminants, such as pesticides and pharmaceuticals. An increasing number of these compounds are found in drinking water.

An important advantage of this technology is that chlorine is no longer needed for primary disinfection at PWN. This eliminates the environmental and safety risks associated with the use of chlorine. Further, it appears that UV/hydrogen peroxide may be a promising process for meeting LT2 requirements.

4.3.10 Ozone/Hydrogen Peroxide

Until the late 1990s the only commercial water treatment applications of ozone in combination with hydrogen peroxide were in Europe. This is because the European Community (EC) adopted a restrictive pesticide standard that requires a MCL of any single pesticide of 0.1 mg/L, and no more than 0.5 mg/L of total pesticides. In the many European plants already using ozone, it was quickly found that ozone alone could not meet the pesticide regulation, and additional treatment was required.

The combination of ozone and hydrogen peroxide is one of a number of processes referred to as Advanced Oxidation. Advanced oxidation processes involve the generation of extremely reactive hydroxyl radicals. The oxidation potential of hydroxyl radicals is greater than any other oxidant with the exception of fluorine, and over twice that of chlorine. One method of producing hydroxyl radicals is to mix hydrogen peroxide with ozone containing water. Since many European plants already use ozone, France and Britain retrofitted their treatment plants to add hydrogen peroxide to the ozone contactors. The resulting hydroxyl radical generation was sufficient to easily meet the EC pesticide regulation.

Oxidation in the ozone/hydrogen peroxide process (peroxone) occurs due to two reactions: direct oxidation of compounds by aqueous ozone and oxidation of compounds by hydroxyl radicals produced by the decomposition of ozone.

The ratio of direct oxidation with molecular ozone is relatively slow compared to hydroxyl radical oxidation, but the concentration of ozone is relatively high. On the other hand, the hydroxyl radical reactions are very fast, but the concentration of hydroxyl radicals under normal ozonation conditions is relatively small. In the peroxone process, the ozone residual is short lived because the added peroxide greatly accelerates the ozone decomposition. However, the increased oxidation achieved by the hydroxyl radical greatly outweighs the reduction in direct ozone oxidation because the hydroxyl radical is much more reactive. The net result is that oxidation is more reactive and much faster in the peroxone process compared to the ozone molecular process.

The use of ozone in combination with peroxide has a major advantage over use of ozone alone, in that ozone can be used alone as a primary disinfectant, which will produce easily oxidized compounds from the natural occurring organic material in the source water. Left alone, these organics would contribute to TTHM and HAA5 formation during chlorination. However the addition of peroxide to the ozone containing water will produce hydroxyl radicals that will complete the oxidation of residual organics and result in significantly lower chlorine DBP.

The Metropolitan Water District of Southern California is in the process of converting all of their water treatment plants to peroxone. MWD conducted an evaluation and operated a 5.5 MGD pilot plant to compare the cost of ozone and GAC vs. peroxone in their five water treatment plants to produce water with a target TTHM level of 20mg/L. Peroxone was projected to be $150,000,000 lower in cost. The Jensen plant (750MGD) and the Mills plant (350MGD) have been converted to peroxone.

References:

4-1) USEPA. 1997a. *Low-Pressure Membrane Filtration for Pathogen Removal.* EPA 815-C-01-001, April, 2001.
4-2) USEPA. 1999. *Alternative Disinfectants and Oxidants Guidance Manual.* EPA815-R-99-014, April, 1999.
4-3) Emedicine, WEBMD.
4-4) USEPA. 1999. *Alternative Disinfectants and Oxidants Guidance Manual.* EPA815-R-99-014, April, 1999.

5. Summary of Survey of Current Utility Practices and Plans

Of the many water treatment plants that were contacted, information from 12 plants was obtained. Key observations are summarized below:

- The annual average flow rate ranged from 12 MGD to 60 MGD, although not all respondents provided average flow information.
- Only 1 of the 12 plants obtained its water from a ground source. The other 11 plants used surface water for their supply.
- 9 of the plants had coagulation or flocculation.
- 11 of the plants had filtration; only the plant whose source water was ground water did not conduct filtration.
- 1 plant uses membrane filtration, 10 plants use granular filtration
- 5 of the plants use chlorine gas.
- 9 of the plants use sodium hypochlorite or chloramine.
- 5 of the plants have VFDs
- 5 of the plants have high efficiency motors

Figure 5.1
The Number & Percentage of Survey Respondents Treating the Source Water Indentified

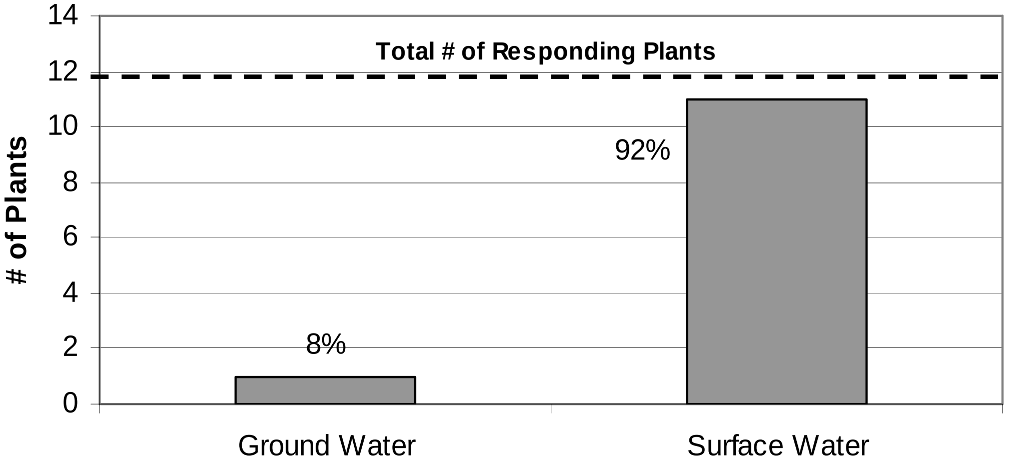
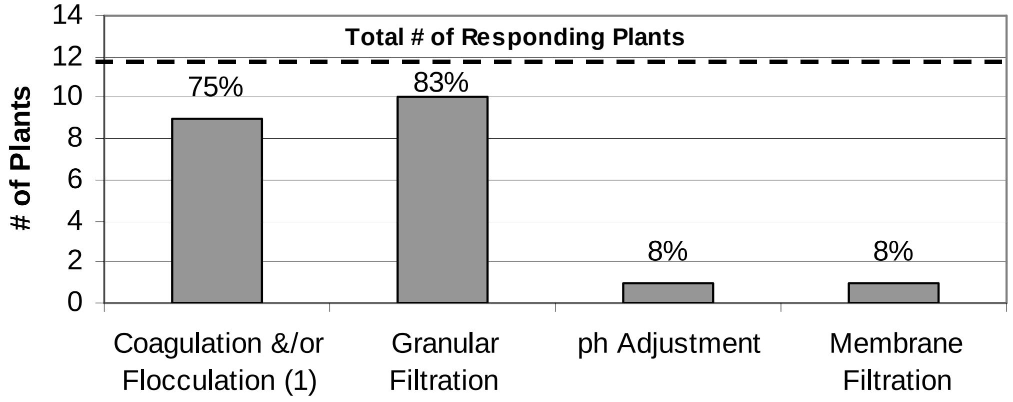
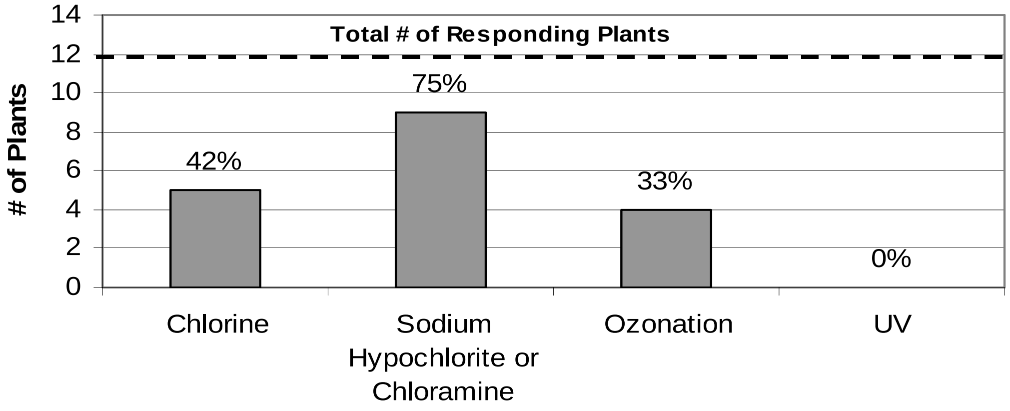


Figure 5.2
The Number & Percentage of Survey Respondents Providing the Identified On-Site Treatment



(1) All plants that coagulate or flocculate also filter.

Figure 5.3
The Number & Percentage of Survey Respondents Using the Identified Method of Disinfection (1)



(1) Some plants use more than 1 method of disinfection.

Figure 5.4
The Number & Percentage of Survey Respondents Using the Identified Energy Efficiency Measure

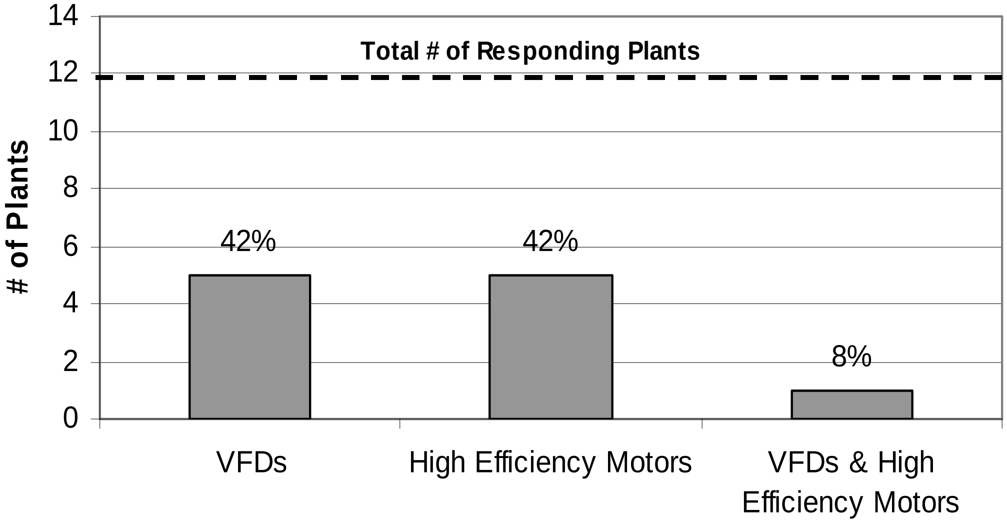


Table 5.1. Summary of Current Utilities' Operations

Plant	Construction Date	Upgrades to Treatment	Design Flowrate (MGD)	Average Flowrate (MGD)	Source Water: surface or ground	Off-site Pretreatment	On-site Pretreatment	Disinfection	Changes Planned	Energy Considerations	SCADA
Sunol Filtration Plant	1966	1972, 2000	160	60	Surface	One site- potassium permanganate other site- CO2	Dual media filtration, coagulation, flocculation, sedimentation	Chlorine Dioxide and chloramine	Potential to replace potassium with ozone	Not answered	Yes
Harry Tracy Filtration Plant	1972	1988, 1990	160	60	Surface	None	Dual media filtration, coagulation, flocculation, sedimentation	Sodium hypochlorite, ozonation, chloramine	Change from on-site ozone generation to LOX	VFDs on large pumps	Yes
Montevina Filter Plant	1970	1993	30	12	Surface	None	Direct filtration, coagulation, flocculation	Sodium hypochlorite	Potential to add ammonia	High efficiency motors	Yes
Saratoga	1950	na	5	2 (for 9 month seasonal operation)	Surface	None	Membrane filtration	Sodium hypochlorite	None	VFDs on large pumps	Yes
Sobrante	1950	2000	60	20	Surface	None	Dual media filtration, coagulation, flocculation	Sodium hypochlorite, ozonation, chloramine	None	Not answered	Yes
Wohler	1960	1990	80	40	Ground	None	Caustic soda	Chlorine gas	None	High efficiency motors, off peak pumping	Yes

Table 5.1 Continued

Plant	Construction Date	Upgrades to Treatment	Design Flowrate (MGD)	Average Flowrate (MGD)	Source Water: surface or ground	Off-site Pretreatment	On-site Pretreatment	Disinfection	Changes Planned	Energy Considerations	SCADA
Stockton	1975	1990	50	38	Surface	Occassional potassium permanganate	Dual media filtration, coagulation, sedimentation	Sodium hypochlorite, chlorine gas	None	High efficiency motors, VFDs on large pumps	No
Bowman Auburn	1970	na	5	Not answered	Surface	None	Coagulation, flocculation, sedimentation, gravel filter	Chlorine gas	Sodium hypochlorite to replace chlorine gas	VFDs on large pumps	Yes
Foothill	1978	2003	40	Not answered	Surface	None	Dual media filtration	Chlorine gas	None	VFDs on large pumps	Yes
Alta	1950	na	0.3	Not answered	Surface	None	Direct Filtration, coagulation	Sodium Hypochlorite	None	Not answered	No
Bollman	1968	1996	75	42	Surface	None	Dual media filtration, coagulation, flocculation, sedimentation	Ozonation, sodium hypochlorite, chloramine	None	Some high efficiency motors	Yes
Randall Bold	1993	na	40	15	Surface	None	Dual media filtration, coagulation, flocculation, sedimentation	Ozonation, chlorine gas, chloramine	None	Some high efficiency motors	Yes

6. Strategies for Compliance with Regulations Under Development

The LT2 and DBP2 rules are being implemented by the EPA in an effort to balance the risks to public health from microbial contamination (*Cryptosporidium*) and harmful chemical by-products of disinfection such as TTHM and HAA5. Both rules require two years of monitoring: for *Cryptosporidium*, E-coli, and turbidity levels in source water under LT2, and for concentrations of TTHM and HAA5 at critical locations within the distribution system under DBP2. Any compliance strategy for these rules must consider source water quality, existing plant processes, plant capacity, staffing levels, capital cost, total operating and maintenance in addition to energy cost and other constraints.

DBP2
Plants that have relatively small violations in Locational Running Annual Average for TTHM or HAA5 may be able to achieve compliance by improving water movement within the impacted sections of their distribution system. Water residence time is a key factor in the production of DBP particularly at the periphery of a distribution system. Better water management such as increased line flushing or quicker turnover within storage tanks may be a cost effective option to achieve compliance for minor violations.

Plants with more serious violations, must within 6 years, adopt treatment alternatives to bring their system into compliance. There are two basic approaches to control DBP and *Cryptosporidium*: (1) provide a barrier to remove DBP precursors and cysts, or (2) change the primary/secondary disinfectant. As a result it should be possible for plants with violations of both DBP and LT2 to select treatment options that will provide compliance with both rules.

DBP Precursor Removal
DBP precursors can be controlled by several processes. Improved filtration, particularly if it incorporates a biological treatment phase, will significantly reduce DBP precursors. Filtration removes a portion of the organic precursors, and provides a media for biological growth that can further reduce precursor levels. Aerobic treatment decomposes a portion of the organic material in the water into CO_2 and water.

Riverbank filtration (as practiced extensively in Europe) provides combined long duration filtration and biological treatment. Riverbank filtration is currently in use in the US in several plants and under consideration by others. A slow sand filtration system will also provide filtration in a biologically active environment.

GAC, if allowed to develop biological activity, can also achieve a high degree of precursor removal with the added advantage of adsorptive capability after biological treatment. It is extremely important to provide good pretreatment prior to GAC processing. Such pretreatment in conjunction with proper distribution of flow to multiple GAC modules will reduce both capital and operating costs.

Membranes are also highly effective at removing DBP precursors as well as cysts. Combinations of micro-filtration and ultra-filtration membranes can achieve very low precursor levels. As with GAC a high level of pretreatment is essential to avoid increased capital cost and high reject flows. Reject flow treatment and disposal can be a problem for many plants. Proper pretreatment will also minimize backwash flows and membrane cleaning costs. Despite the cost and reject disposal issues, more than a hundred drinking water plants in the U.S. are using membranes and 28 of those plants are in California.

Alternative Disinfectants
For plants with DPB violations, which improved water management cannot correct, a change of disinfectant is an option. For systems using chlorine, chlorine dioxide, ozone or UV as primary disinfectants, switching from chlorine as the residual disinfectant to chloramine can effect a reduction in DBP formation of 60% or more. This reduction is so significant that a number of plants have already

switched to chloramine residual disinfection. Chloramine as a residual must be well controlled to prevent the bacterial generation of nitrite/nitrate from the nitrogen in chloramine.

A change of primary disinfectant from chlorine or hypochlorite to ozone, chlorine dioxide or UV will also reduce DBP, as they do not produce chlorinated byproducts. All three can also provide varying levels of *Cryptosporidium* inactivation.

The disinfection/advanced oxidation processes (ozone/peroxide, ozone/UV and UV/peroxide) can also achieve a reduction in DBP precursors and trace contaminant removal by hydroxyl radical oxidation.

LT2

Plants whose source water monitoring for *Cryptosporidium* places them in a category or bin that requires additional treatment have a variety of options. Many of the options for control of DBP precursors are also effective for achieving a range of log reduction of *Cryptosporidium*. A 0.5-log reduction credit is given for a watershed protection/source water improvement program. In the pretreatment area, riverbank filtration or pre-sedimentation or two stage lime softening can each provide a 0.5-log reduction. Bag and cartridge filtration are eligible for 2-log reduction, or 2.5-for two bag or cartridge filters in series. Slow sand filters can provide a 2.5-log credit, and membrane treatment must be consistent with performance in a membrane challenge test but typically at least a 2-log removal credit. Credits are also available from demonstration of plant performance, and 0.5-log credit if combined filter effluent turbidity is 0.15 NTU or less in 95% of measurements each month.

Finally, the EPA recognizes chlorine dioxide, ozone and UV as effective technologies for c*ryptosporidium* inactivation, in accordance with EPA published contact time (CT) values for chlorine dioxide and ozone at various water temperatures, and dose requirements for UV.

As a practical matter, chlorine dioxide at high concentrations and long contact times may produce a 1.0-log *Cryptosporidium* reduction depending on water temperature. Ozone should be able to achieve 1 to 1.5-log *Cryptosporidium* reduction also dependent on water temperature. UV at appropriate dose can achieve a 3+log reduction for both Giardia and *Cryptosporidium* regardless of water temperature.
The disinfection/advanced oxidation processes (ozone/peroxide, ozone/UV and UV/peroxide) can produce log reductions of *Cryptosporidium* consistent with the EPA CT values for ozone or dose requirement for UV and also reduce DBP precursors through hydroxyl oxidation.

Residual disinfection is required to safeguard the water. Only chlorine, chlorine dioxide and monochloramine provide residual disinfection in the distribution system. Chloramines are more stable than free chlorine in the distribution system, providing residual treatment of the water supply.

There are multiple combinations of treatments that can be used to achieve compliance with both rules. For example a plant using chlorine as the primary disinfectant might use GAC or membranes to reduce DBP precursors, followed by UV for *Cryptosporidium* inactivation with chloramine residual disinfection. The possible combinations for simultaneous compliance are numerous. The ultimate selection will depend on analysis of a particular plant's performance, staff capabilities, budget and a host of other factors. A close reading of both rules indicates that the EPA considers UV an attractive option as a disinfectant for both DBP and *Cryptosporidium* inactivation.

The appeal of the combination disinfectant/advanced oxidation processes may be of significant value should the U.S. follow the European Community in regulating pesticide residues in water. Such processes could also be attractive in the event of future regulation of endocrine disruptors, pharmaceuticals and other trace organics.

7. Comparison of Disinfection Techniques

Comparing disinfectants is very difficult as many factors influence the selection of the optimum combination of disinfection processes for any particular plant and the appropriate amount of each disinfectant to be used. Among the most important factors are: the source of water, its quality and the treatment processes utilized. High quality groundwater may require little treatment other than a low dose of chlorine or chloramines to provide disinfection and a residual disinfectant during distribution. In contrast, surface water may have significant levels of silt, microbial, organic and inorganic contaminants. Pre-oxidation is needed for some treatment processes but not for others. The size of the treatment facility as well as the type of existing treatment processes are also important considerations to the selection of an appropriate disinfection technique. For those plants where monitoring shows an inability to comply with the developing LT2 and DBP2 rules, the choice of primary and secondary disinfection can be the critical factor for achieving compliance. While it is beyond the scope of this project to compare disinfection processes in detail, it is possible to rank the various disinfectants qualitatively on the basis of certain performance characteristics as shown in Table 7.1.

Among the advanced drinking water treatment techniques, three have a significant impact on the amount of energy used at the treatment plant. The treatment techniques are ozone, UV radiation and high-pressure membrane filtration.

Table 7.1. Criteria for Comparison of Disinfectants

Disinfectant	Chlorine	Chlorine Dioxide	Hypochlorite	Ultraviolet	Ozone	Chloramine	O3 /UV	O3/Perox	UV/Perox
Performance Characteristics									
Microbial Control									
Bacteria	4	3	3	4	4	2	4	4	4
Giardia	2	4	2	4	4	1	4	4	4
Viruses	3	3	3	3	2	2	2	2	4
Crypto	1	4	1	4	3	1	3	3	4
By-products	1	4	1	4	3	1	3	3	4
Residual Disf.	3	2	3	0	0	1	0	1	1
Elec. Use	low	medium	low	high	high	low	high	high	high
Capital Cost	low	medium	low	medium	high	low	high	high	high
O & M Cost	low	medium	low	medium	high	low	high	high	high
Safety	high	medium	low	low	medium	low	medium	medium	medium
Complexity	low	high	low	low	high	low	high	high	medium

Rating System
Disinfection Efficacy: 4 – Excellent; 3 – Good; 2 – Fair; 1 - Poor
Other Characteristics: low - Advantageous; medium – Satisfactory; high - Unfavorable

Ozone

On-site energy consumption for ozonation is a function of such factors as whether air or pure oxygen is used for the production of ozone, the ozone dosage needed, and the scale (size) of the plant. Generalized energy requirements for key processes for producing ozone are provided in Table 7.2.

Table 7.2 Estimated Energy Requirement for Ozone Generation

kWh/lb O_3 Generated	kWh/lb to dry air	kWh/lb for O_3 Contacting	kWh/lb for off gas Destruction	Total kWh/lb of O_3 Generated
8 (air)	3	0*	2	13
5 (6% O_3 from O_2)	N.A.**	0*	2	7 ***
7.5 (16% O_3 from O_2)	N.A. **	0*	2	9.5 ***

* For bubble diffuser contactors. All other contactors require additional Energy.
** Not applicable: liquefied oxygen would be transported to the site.
*** On-site energy requirement - excludes power for oxygen production.

Source: Ozone Reference Guide EPRI CR-107260

As can be seen from the above, the on-site energy requirement to generate ozone from pure oxygen is roughly half to three-fourths the amount to generate ozone from air.

Typical ozone dosage for pre-oxidation (pretreatment) is 1.0 mg/l to 2.0 mg/l and the dosage for disinfection 4.0 mg/l to 6.0 mg/l. Based on information from Table 7.2, the estimated energy consumption would be as follows:

- A medium-to-large sized plant using ozone from pure oxygen for pre-oxidation (pretreatment) might use an ozone dose of 1.5 mg/l, which would require 119 kWh/MG to produce the ozone. (Based on 9.5 kWh/lb of O_3)
- A medium-to-large sized plant using ozone from pure oxygen for disinfection might use an ozone dose of 5.0 mg/l, which would require 398 kWh/MG to produce the ozone. (Based on 9.5 kWh/lb of O_3)

In the late 1990's the Milwaukee, WI and Green Bay, WI plants implemented ozonation for pretreatment while the Oshkosh, WI plant implemented ozonation for disinfection. Based on the limited data available from the report, *Energy Use at Wisconsin's Drinking Water Facilities*, it appears the energy consumption at the Milwaukee and Green Bay plants increased from approximately 1,400 kWh/MG to about 1,600 kWh/MG and from 1,800 kWh/MG to about 1,900 kWh/MG, respectively. Thus, the increases were approximately 200 kWh/MG and 100 kWh/MG for the two plants. The increased energy use for pretreatment is consistent with the estimate of energy use for ozone pretreatment based on information from the Ozone Reference Guide.

The energy consumption at the Oshkosh plant changed from approximately 1,000 kWh/MG to 1,600 kWh/MG, an increase of 600 kWh/MG.

UV Radiation

UV disinfection of drinking water has been used on a limited basis in the U.S., however its use is becoming more widespread. Energy consumption for UV radiation is a function of the needed UV dose, flow rate, water quality, type and amount of contaminants, and other factors. There is limited data on typical dose rates of UV radiation for disinfection drinking water in the U.S. UV radiation is commonly used for disinfection in Norway. Dose rates in the range of 40 mj/cm^2 are typical in Norway. (Ref. 7-3) UV doses for 2 and 3-log inactivation of bacteria are in the range of 20 to 36 mj/cm^2. Dose rates in the range of 30 to 180 mj/cm2 have shown to be needed to control viruses. Although investigations by Rice & Hoff, 1981; Karanis et al., 1992) indicated UV radiation was not very effective for controlling *Cryptosporidium* oocysts. More recent studies have shown UV radiation in the dose range around 40 mj/cm^2 is effective for controlling *Cryptosporidium* oocysts. Some treatment plants might opt to design for inactivating bacteria and *Cryptosporidium* oocysts but not for control of viruses, intending to control viruses by adding a chlorine-based disinfectant that would also provide residual disinfectant for the distribution system.

The amount of UV required to achieve disinfection is dependent upon several parameters, including turbidity and the concentration and type of contaminants. However, as an example to compare the energy consumption for low pressure and medium pressure UV lamps, a dose of 180 mj/cm^2 using low-pressure UV lamps would require an energy consumption of approximately 77 kWh/MG. Using medium-pressure UV lamps to apply 180 mj/cm^2, would require an energy consumption of approximately 160 kWh/MG. Although there is a substantial energy savings to the use of the low-pressure lamps, the advantages of medium pressure UV systems, including: fewer lamps, lower cleaning and maintenance costs and easier dose control at reduced flow has made medium pressure UV systems the usual choice for drinking water disinfection for plants that treat a medium-sized or larger flow. (Ref. 7-4)

Using the energy consumption rates identified above, a 5 MGD drinking water plant using a medium pressure UV system would consume about 800 kWh/day. At a power cost of $.10/kWh the energy cost would be approximately $29,000/yr. The annual cost savings from using low pressure UV would be about $15,000/yr. The difference in amortizing the capital cost of the systems in addition to differences in maintenance costs would need to be assessed to determine the more cost-effective system.

Membrane Filtration

Although ultra-filtration is not directly comparable to the disinfection techniques discussed previously, ultra-filtration is effective in removing bacteria and viruses without producing DBP. As discussed in Section 4, the use of ultra-filtration at water treatment plants has been increasing dramatically over the last 10 years. However, the ultra-filtration process uses a significant amount of energy. The primary energy costs in membrane filtration systems are for operating the feed water pump, backwash pumps, compressors and residual pumps. Table 7.3 provides information annual power cost from 3 bids submitted for the construction of a 5.2 MGD membrane treatment facility. Power consumption was estimated based on the assumption that the power cost was based on an average plant flow of 5.2 MGD for 365 days per year.

Table 7.3 Estimated Power Consumption for 5.2 MGD Membrane Water Treatment Facility

		Supplier A	Supplier B	Supplier C	Average
Operational costs					
	Feed pump power ($/yr)	38,617	37,485	57,000	
	Backwash pumping ($/yr)	1,535	18,559	0	
	Residuals pumping ($/yr)	2,111	5,805	2,100	
	Air compressor power ($/yr)	6,298	1,000	15,200	
Total of power costs ($/yr)		48,561	62,849	74,300	61,900
Annual Power Consumption (kWh/yr) (1)		485,610	628,490	743,000	619,000
Power Consumption (kWh/MG)		**256**	**331**	**391**	**326**

Source: Micro-filtration and Ultra-filtration Membranes for Drinking Water, AWWA Manual M53, 2005.

(1) Bids were based on energy cost of $.10/kWh. Assumed that annual power consumption was based on an average of 5.2 MGD for 365 days.

References:

7-1) *Energy Use at Wisconsin's Drinking Water Facilities*, Elliott, T., et al, Wisconsin Focus on Energy and The Energy Center of Wisconsin, ECW Report Number 222-1, July, 2003.
7-2) Ibid.
7-3) Norwegian Institute of Public Health
7-4) *Alternative Disinfectants and Oxidants Guidance Manual*, EPA Office of Water, EPA 815-R-99-014, April 1999.

8. Baseline Design, Energy Efficiency Measures and Incentives

This Section addresses the baseline design for water treatment plants and provides incentive information about energy efficiency measures for treatment techniques and equipment choices.

8.1 Baseline Design, Energy Efficiency Measures and Incentives for Treatment Techniques

Conventional Treatment Techniques

For the conventional treatment techniques such as screening, aeration, coagulation, flocculation, sedimentation and granular filtration, the primary energy consumption is a result of the use of a motor for pumping water. **The baseline for these treatment techniques is use of EPAct motors.** The primary energy efficiency measure is use of premium efficient motors.

Membrane Filtration

The baseline for membrane filtration projects is use of EPAct motors and no or limited pretreatment. The two main energy efficiency measures for membrane filtration systems are pretreatment of the water prior to filtration and the use of premium efficient motors to achieve the water pressure (or vacuum) needed for filtration. Pretreatment could be sedimentation, coagulation & sedimentation or coagulation, flocculation & sedimentation.

UV Disinfection

The baseline for UV disinfection projects is use of medium pressure UV lamps. The main energy efficiency measure is the use of low-pressure UV lamps.

Ozone

The baseline design for ozone systems is on-site generation of enriched oxygen gas concentration prior to ozone production and fine bubble diffusion of the ozone in the water. The main energy efficiency measure is transport of oxygen (in liquid form, LOX) to the treatment facility. Since LOX transport to the site has a lower capital cost than on-site generation of enriched oxygen, there is no incentive for the selection of that option. There is no energy efficiency improvement to fine bubble diffusion, since fine bubble aeration is part of the usual design.

Ozone/Peroxide

The baseline and efficiency measures for ozone/peroxide are the same as for ozone.

UV/Peroxide

The baseline and efficiency measures for UV/peroxide are the same as for UV disinfection.

Raw Water Pumping

The baseline for raw water pumping is use of EPAct motors and throttling or by-pass to achieve variable flow rates. The main energy efficiency measures are use of premium efficient motors and use of a VFD. However, if the treatment facility is designed in such a way that it requires use of a VFD then it is not eligible for an incentive payment. Note: installation of a VFD does not guarantee energy savings. A fixed rate of pumping for an appropriately sized pump may be as efficient or more efficient than use of a VFD.

Finished Water Pumping

The baseline for finished water pumping is use of EPAct motors. The main energy efficiency measure is use of premium efficient motors. Another efficiency measure is use of a booster pump for those customers located at a higher elevation rather than raising the pressure of the whole distribution system in order to serve the high elevation customers. Also, a VFD could be an efficiency measure.

8.2 Baseline Design, Energy Efficiency Measures and Incentives for Equipment Choices

Motors

The baseline for motors is constant speed, EPAct motors. One energy efficiency measure is use of premium efficient motors. The Energy Policy Act (EPAct) requires that most motors sold in the U.S. meet specific minimum energy efficient standards. The Consortium for Energy Efficiency (CEE) developed a standard for Premium Efficiency Motors (PEM). PEMs exceed the efficiency of EPAct motors by approximately

1% to 3%, depending primarily on the size of the motor. PEMs use energy more effectively, and their superior design provides a higher power factor. As a result, PEMs require less maintenance and are more reliable. Pump motors typically account for about 80% of the energy costs in water treatment facilities, and the lifetime energy cost to run a continuous duty motor are 10 to 20 times higher than the original motor cost.

Use of a VFD can be an energy efficiency measure when there is significant variability to the flow rate. However, it is not appropriate to pay an incentive for a VFD when use of a VFD is required by the system.

Pumps

The baseline for pumps is standard components and interior surfaces. One energy efficiency measure is the use of highly durable components that do not wear and reduce efficiency as quickly as conventional components. A second energy efficiency measure is to line the interior of the pump with a material that reduces the friction. Another efficiency measure is use of a booster pump when a portion of the service area is located at a significantly higher elevation than the other customers. Use of a booster pump avoids the energy use of maintaining the entire distribution system at a higher pressure than would otherwise be needed.

Blowers and Compressors

Blowers are typically used to provide volumes of air at 6 to 10 PSI above atmospheric pressure. Compressors are typically used to provide volumes of air at 75 PSI to 140 PSI. Maximizing energy efficiency can be accomplished by having appropriately sized blowers and compressors to produce the needed flow rates; operating blowers and compressors within the design operating range for flow rate and pressure and as with pumps, maintaining blower and compressor components within manufacturer’s specifications. A compressor uses as much as five times more energy to provide the same volume of air as provided by a blower. It is, therefore, very important to utilize a blower when the lower air pressure is adequate. **The baseline for a blower is constant speed, multi-stage unit.** The primary energy efficiency measure is use of a high efficiency, single stage blower.

If compressed air is needed on the site, it is important to provide the correct amount of air at the correct pressure. An over-sized compressor costs in both first cost (purchase) and operating cost (energy). Air supplied at a pressure higher than needed dramatically increases operating costs. Even with the appropriately sized compressor, there are usually periods of operation when less than full capacity is needed from the compressor. Having appropriate controls will help in reducing energy costs when lower airflow rates are required. There are numerous approaches for providing capacity control to compressors, including modulation, unloading, variable displacement and variable speed. Since the annual operating cost of a compressor is generally near the purchase price of a new compressor, it is very important to lower the annual operating cost by selecting an appropriately sized compressor with efficient capacity control. A variable airflow demand usually makes a good application for a VFD. If load/unload controls are selected, sufficient air storage volume must be provided to allow the compressor to operate efficiently. Maintenance of the compressor and its distribution system can have a dramatic effect on operating costs. It is not unusual to see leaks in the distribution system consuming 25% of the energy used by the compressor. If it is necessary to have more than one compressor operating, it is imperative the compressors are operated in a coordinated manner. Finally, avoid using compressed air for any task that can be reasonably performed in an alternate way. An air operated diaphragm pump will consume six times the energy of an electric pump doing the same pumping task. **The baseline for compressors is constant speed with inlet modulation and unloading**. An incentive can be paid for installing load/unload controls and for installing a VFD provided the VFD is not required for flow control. **The baseline for a compressed air system with multiple compressors is minimal coordination of their operation.** The primary energy efficiency measure is use of a sequencer to coordinate compressor operation.

Variable Frequency Drives

A VFD is an electronic controller that adjusts the speed of an electric motor by modulating the power delivered to the motor. A VFD provides continuous control, allowing the motor speed to be matched to the specific demands of the work being performed. VFDs enable operators to fine-tune the flow rate while reducing costs for energy and maintenance.

For applications where flow requirements vary, mechanical devices such as flow-restricting valves are occasionally used to control flow. This method for controlling the output of a pump or a blower uses excessive energy and usually adds substantial wear on the pump or blower. VFDs enable pumps and blowers to accommodate fluctuating demand, running pumps and blowers at lower speeds and drawing less energy while still providing the needed flow rate. VFDs work with most three-phase electric motors, so existing pumps and blowers that have throttling devices can be retrofitted. VFDs can also be specified for new equipment.

Another advantage of VFD is in motor starting. Single speed drives start motors abruptly, subjecting the motor to high torque and current surges up to 10 times the full-load current. In contrast, VFDs provide a “soft start” capability, gradually ramping up a motor to operating speed. A soft start lessens: the energy demand, mechanical and electrical stress on the motor, and maintenance costs and extends motor life.

Energy savings from a VFD can be significant. A VFD controlling a motor that usually runs less than full speed can substantially reduce energy consumption over a motor running at constant speed for the same period. As an example, for a 25 hp motor running 23 hours per day (2 hours at 100% speed: 8 hours at 75% speed: 8 hours at 67%: and 5 hours at 50%) a VFD can reduce the energy use by 45%. At $0.10 per kWh, this saves $5,374 annually. Because this benefit varies, depending on the particular characteristics of the system - variables such as pump size, load profile, and amount of static head, it is important to calculate the costs and benefits for each application before specifying the use of a VFD. VFDs are reliable, easy to operate, and increase the degree of flow control. **The baseline for flow control is constant speed motors, throttling pump or blower, and using a by-pass to reduce flow.** Situations that require the use of a VFD for flow control do not qualify for an incentive.

Valves

Valves often play a critical role in water treatment plants by controlling flow and pressure. However, valves can produce significant head loss, thus dramatically increasing the energy required for pumping. Variable frequency drives provide a much more energy efficient mechanism for controlling flow. There are many types of valves used in water treatment facilities, including:

- Swing check valves – have higher head loss, but provide adjustable closing
- Ball check valves – have low head loss and have slow closing speed
- Flapper check valves – have very low head loss, but slow, non-adjustable closing speed

The baseline for valves is a standard high head loss valve. The primary energy efficiency measure is use of a low head loss valve or in some situations, a VFD.

Water Storage Capacity

Limited storage capacity can result in the need for a larger capacity pump, more frequent pump start-up and reduce the opportunity for controlling time-of-day pumping. **The baseline for storage is nominal capacity**. The primary energy efficiency measure is increased storage capacity beyond the nominal amount.

Information and Control Systems

Inadequate or inaccurate sensors would adversely affect the energy efficiency with which processes and pumping operations are managed. Conversely, utilizing accurate plant information and controls systems would result in greater energy efficiency and provide the information for efficiently producing treated water. **The baseline is limited system data collection and automation.** The primary energy efficiency measure is an integrated data collection and automated control system. One example of a very highly integrated data collection and automated control system is the East Bay Municipal Utility District (EBMUD) Energy and Water Quality Management System (EWQMS) that generates an optimized pump schedule for the ensuing 24 to 48 hours. [For more detailed information, refer to a paper on EBMUD's EWQMS delivered at ACE in June 2005.]

Low Friction Coatings

Pipes made of smooth material, such as polyvinyl chloride, when compared with traditional cast iron pipes, reduce friction losses. Pipes with a lower friction coefficient can reduce pumping energy requirements as much as 6%. Applying certain resin and polymer coatings to the insides of a pump can reduce energy requirements by another 1% to 3%. (Ref. 8-1) **The baseline is standard piping, such as ductile iron pipe.** The primary energy efficiency measure is use of liner or coating to reduce friction.

Efficient Lighting

The baseline for lighting is compliance with Title 24.

Energy efficiency measures include:

- Use of motion detectors to activate lights when a room is in use
- Use of photocells for controlling exterior lighting
- Utilize day-lighting
- Install multi-level switching

Table 8.1 contains a summary of the baseline design and corresponding energy efficiency measures that would qualify for an incentive under the New Construction incentive program.

References:

8-1) *Watergy: Taking Advantage of Untapped Energy and Water Efficiency Opportunities in Municipal Water Systems*, Alliance to Save Energy, http://Watergy.org)

8-2) Case Study: Energy and Water Quality Management System Saves Electricity Dollars, AWWARF. 2006.

8-3) *Energy Use at Wisconsin's Drinking Water Facilities*, Energy Center of Wisconsin, Report 222-1, July 2003.

Table 8.1 Baseline Design and Example Energy Efficiency Measures for PG&E's New Construction Program

Category		Baseline Design	Energy Efficiency Measure Example	New Construction Program Incentive? Y - N - Maybe
Treatment Technique				
	Screening Aeration Coagulation and Flocculation Sedimentation Granular Filtration Ion Exchange	EPAct motors	Premium efficient motors	Y
	Membrane Filtration	EPAct motors	Premium efficient motors	Y
		Limited pretreatment	Coagulation/Flocculation/Sedimentation	Y
	UV Disinfection	Medium pressure lamps	Low pressure lamps	Y
	Ozone	Fine bubble diffusers	No	N
		Ozone generation starting from air	Ozone generation starting from LOX	Maybe
	Ozone/Peroxide	same as ozone	same as ozone	same as ozone
	UV/Peroxide	Medium pressure lamps	Low pressure lamps	Y
	Raw Water Pumping	EPAct motors	Premium efficient motors	Y
		Throttling or by-pass	VFD	Maybe (1)
	Finished Water Pumping	EPAct motors	Premium efficient motors	Y
		High pressure for entire system	Booster pump for high elevation customers	Y
		Throttling or by-pass	VFD	Maybe (1)
Equipment				
	Motors	EPAct motors	Premium efficient motors	Y
		Constant speed	VFD	Maybe (1)
	Pumps	Standard components	High durability components	Y
		Standard interior surface	Liner to reduce friction	Y
	Booster pump	High distribution system pressure	Localized booster pump	Y
	Blowers	Constant speed, multi-stage	High efficiency single stage	Y
	Compressors	Modulating	Load/unload with receiver	Y
		No sequencer	Sequencer	Y
	Valves	High head loss	Low head loss valve or VFD	Y
	Water storage capacity	Standard capacity	Increased storage capacity	Maybe
	Information and controls	Limited data collection & controls	Integrated data collection & control system	Y
	Piping	Standard interior surface	Liner or coating to reduce friction	Y
	Lighting	Title 24	Motion detector to activate lighting	Y
			Multi-level switching	Y
			Use of day-lighting	Y
			Photocell to control exterior lighting	Y

(1) Unless a variable fluid flow is required by the process.

9. Conclusions

The water treatment industry is in a major transition in which new regulations impose more stringent limits on the allowable concentration of impurities. In addition, the regulations impose requirements to control the concentration of impurities not previously required to be controlled. For many treatment plants, the regulations are likely to require the use of relatively new treatment techniques such as ozone, ultraviolet radiation, hydrogen peroxide, chlorine dioxide or membrane filtration. Some plants will need to use a combination of treatment techniques such as ozone/ultraviolet radiation or ozone/peroxide. The selection of the appropriate treatment techniques will depend on several factors, such as the source of the water to be treated, the specific contaminants in the water and their concentration and existing treatment processes. Because of the variation in the contaminants in the water from each source, the applicable treatment techniques used will vary for each facility. As shown in Table 9.1, the new treatment techniques require significantly greater use of electricity than the typical treatment techniques used at the current time.

Table 9.1 Comparative Energy Use for Various Treatment Techniques

Comparative Energy Use for Various Treatment Techniques		Energy Use (kWh/MG) (1)
Ground water plant (Chlorination)		
	Small	10
	Large	10
Typical Surface water plant		
	Small	144
	Large	78
Ozone		
	Pre-oxidation	119
	Disinfection	398
UV radiation (medium pressure)		
	Bacteria	40
	Viruses	40 - 180
Ultrafiltration		256 - 391

(1) Typical values

As discussed in Section 3 of this report, water distribution pumping can utilize more than 1,000 kWh/MG. For this reason, energy efficiency programs for water treatment facilities should also include a major focus on the pumping applications.

As discussed in Section 8 of this report, there are some energy efficiency measures applicable to the new technologies that qualify for an incentive payment under PG&E’s New Construction program. Additional energy savings opportunities for the new treatment techniques may be identified by a detailed investigation of the new technologies.

Appendix A

Regulations & Guidance

Current Drinking Water Rules (by date issued) (ALL ABOUT PDF FILES)

Chart of key regulatory dates (2000-2006) PDF file

Drinking Water Regulations

Current Rules

Proposed Rules

Code of Federal Regulations

Guidance & Policy

Drinking Water Standards (List of Contaminants & MCLs)

- National Primary Drinking Water Regulations: Analytical Method for Uranium
- Withdrawal of Direct Final Rule; National Primary Drinking Water Regulations: Analytical Method for Uranium
- National Primary Drinking Water Regulations: Minor Corrections and Clarification to Drinking Water Regulations; National Primary Drinking Water Regulations for Lead and Copper (June 29, 2004)
- National Primary and Secondary Drinking Water Regulations: Approval of Additional Method for the Detection of Coliforms and E. coli in Drinking Water; Final Rule (February 13, 2004) (HTML) (PDF)
- Unregulated Contaminant Monitoring Regulation: Approval of Analytical Method for Aeromonas; National Primary and Secondary Drinking Water Regulations: Approval of Analytical Methods for Chemical and Microbiological Contaminants; Final Rule (October 29, 2002) (read online)
- Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act; National Primary Drinking Water Regulations; and National Secondary Drinking Water Regulations; Methods Update; Final Rule (October 23, 2002) (read online) (PDF) (Fact Sheet)
- Unregulated Contaminant Monitoring Regulation for Public Water Systems; Establishment of Reporting Date: Direct Final Rule (March 12, 2002) (read online)
- Long Term 1 Enhanced Surface Water Treatment Rule (January 14, 2002) (read online) ~ (PDF)
- Unregulated Contaminant Monitoring Amendment to List 2 Rule and Delay of Reporting Monitoring Results (September 4, 2001) - Direct Final Rule
- Filter Backwash Recycling Rule (June 8, 2001) (read online) ~ (PDF)

- Arsenic Rule (Jan 22, 2001) (read online)
- Unregulated Contaminant Monitoring List 2 Rule (Jan. 11, 2001) HTML
- Radionuclides Rule (Dec 7, 2000) (HTML) ~ (PDF)
- Drinking Water State Revolving Fund Rule (Aug 7, 2000) (HTML) ~ (PDF)
- Removal of the MCLG for Chloroform (May 30, 2000) (HTML)
- Public Notification Rule (May 4, 2000) (HTML) ~ (PDF)
- Analytical Methods for Perchlorate and Acetochlor (Mar 2, 2000) (HTML)
- Lead and Copper Rule minor revisions (Dec 20, 1999) (HTML)
- Underground Injection Control Regulations for Class V Injection Wells (Dec 7, 1999) (HTML) ~ (PDF)
- Analytical Methods for Chemical and Microbiological Contaminants and Revisions to Laboratory Certification Requirements (Dec 1, 1999) (HTML)
- Revisions to the Unregulated Contaminant Monitoring Rule. (Sep 17, 1999) (HTML) ~ (PDF)
- Suspension of Unregulated Contaminant Monitoring Requirements for small public water systems (Jan 8, 1999) (HTML)
- Interim Enhanced Surface Water Treatment Rule (Dec 16, 1998) (HTML) ~ (PDF)
- Stage 1 Disinfectants and Disinfection Byproducts Rule (Dec 16, 1998) (HTML) ~ (PDF)
- Consumer Confidence Report Rule (Aug 19, 1998) (HTML) ~ (PDF)
- Variances and Exemptions Rule (Aug 14, 1998) (HTML) ~ (PDF)
- Drinking Water Contaminant Candidate List (March 2, 1998)
- Revisions to State Primacy Requirements (April 28, 1998) (HTML)
- Small System Compliance Technology List for the Surface Water Treatment Rule (Aug 6, 1997) (PDF)
- Withdrawal of 1991 proposed rule on Radon-222 (Aug 6, 1997) (HTML)
- Analytical Methods for Radionuclides (Mar 5, 1997) (HTML)
- Information Collection Rule (May 14, 1996) (HTML) ~ (PDF)
- Stage 2 Disinfectants and Disinfection Byproducts Rule (January 6, 2006)
- National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule (January 7, 2006)

Proposed rules and other notices open for public comment

Newly proposed rules are listed on the Open for Comment page

Proposed Rules and Notices for which the comment period has closed (date closed)

- Unregulated Contaminant Monitoring Regulation (UCMR) for Public Water Systems Revisions
- Agency Information Collection Activities: Proposed Collection; Comment Request; Laboratory Quality Assurance Evaluation Program for Analysis of Cryptosporidium Under the Safe Drinking Water Act, EPA ICR Number 2067.02, OMB Control Number 2040-0246
- Agency Information Collection Activities: Proposed Collection; Comment Request; Underground Injection Control (UIC) Program; EPA ICR No. 0370.18; OMB Control No. 2040-0042
- National Primary Drinking Water Regulations: Analytical Method for Uranium - Proposed Rule
- Disinfectants/Disinfection By-Products, Chemical, and Radionuclides Rules Information Collection Rule (Renewal)
- Microbial Rules Information Collection Rule (Renewal)
- Public Water System Supervision Program Information Collection Rule (Renewal)
- The Final Draft of the Tribal Drinking Water Operator Certification Program Guidelines is available and EPA is requesting comments
- Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act; National Primary Drinking Water Regulations; and National Secondary Drinking Water Regulations; Analysis and Sampling Procedures - Proposed Rule
  - Federal Register Notice
  - More Information
- Drinking Water Contaminant Candidate List 2 (June 1, 2004)
- National Primary Drinking Water Regulations: Minor Corrections and Clarification to Drinking Water Regulations (May 3, 2004)
- Proposed Aeromonas and NPDWR Methods Rule (May 6, 2002)
- Proposed ground water rule (August 9, 2000)
- Proposed radon rule (November 2, 1999)
- Sulfate health effects study (May 12, 1999)

Code of Federal Regulations (PDF files) -- The CFR compiles all rules currently in effect, and is updated annually as of July 1. To view or search these parts in a section-by-section format, or for other federal regulations, visit the Government Printing Office EXIT disclaimer site. You can also try GPO's new E-CFR EXIT disclaimer, which is updated weekly. (ALL ABOUT PDF FILES)

- National Primary Drinking Water Regulations 40 CFR part 141
- National Primary Drinking Water Regulations Implementation 40 CFR part 142

- National Secondary Drinking Water Regulations 40 CFR part 143
- Underground Injection Control Program 40 CFR part 144
- State UIC Program Requirements 40 CFR part 145
- Underground Injection Control Program Criteria & Standards 40 CFR part 146
- State Underground Injection Control Programs 40 CFR part 147
- Hazardous Waste Injection Restrictions 40 CFR part 148
- Sole Source Aquifiers 40 CFR part 149

9.1.1.1.1 Guidance and Policy

- Water Supply Guidance
- Quick Reference Guides
    - Standardized Monitoring Framework (EPA 816-F-04-010 March 2004)
    - Lead and Copper Rule: A Quick Reference Guide (EPA 816-F-04-009 March 2004) (125 K PDF FILE)
- Guidance on new rules:
    - Arsenic Rule
    - Consumer Confidence Report Rule
    - Lead and Copper Rule
    - Microbial and Disinfection Byproducts Rules
    - Public Notification Rule
    - Radionuclides Rules
    - Unregulated Contaminant Monitoring Rule
- Guidance for Small Systems
- Alternative Monitoring Guidelines
- Guidance on the Drinking Water State Revolving Fund Program
- Guidance on Analytical Methods for Drinking Water (1998)
- Manual for the Certification of Laboratories Analyzing Drinking Water
- Guidance on Data/Databases
- Guidance on State Source Water Assessment and Protection Programs (1997)
- Guidance for Future State Ground Water Protection Grants (1997)

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Last updated on Wednesday, March 8th, 2006
URL: http://www.epa.gov/ogwdw/regs.html

California Department of Health Services

Status of Future Regulations: Drinking Water and Recycled Water

Last Update: April 12, 2006

The main steps in CDHS' Drinking Water Program's regulations process include review of the proposed regulation by:

1. CDHS' Office of Regulations (OR) and
2. Budget Office (BO);
3. the Department of Finance (DOF);
4. the Health & Human Services Agency (HHS); and
5. the Office of Administrative Law (OAL), prior to publication in the *California Regulatory Notice Register*. This announces availability of the regulation for
6. a 45-day public comment period (PC-1). There might be
7. a 15-day public comment period (PC-2), but only if changes are made in response to public comments in PC-1. Then we prepare responses to comments and the final regulations package for
8. approval by CDHS Director's Office (DO). Once signed, the package goes to
9. OAL for final review for Administrative Procedure Act compliance—this can take up to 30 working days. Following OAL approval, the regulation is filed with
10. the Secretary of State (SOS), and becomes effective 30 days later.

The following regulations are under development, and are at various stages in the process. Follow the links to proposed or draft regulations, or, if they aren't yet available, to other information.

Status of Regulations Under Development by DHS' Drinking Water Program
(U = underway; X = completed; NLT= expected no later than)

Regulation (Reg. Control No.)	*OR*	*BO*	*DOF*	*HHS*	*OAL*	*PC-1*	*PC-2*	*DO*	*OAL*	*SOS*
Radionuclides (R-12-02)	X	X	X	X	X	X	X	X	NLT ~5/10	.
Disinfection & Disinfection Byproducts (R-62-00)	X	X	X	X	X	X	X	X	NLT ~5/22	.
Public Notification of Violations (R-59-01)	X	X	X	X	X	X	X	.	.	.
Secondary MCLs	X	X	X	X	X	X	X	.	.	.

(R-21-03)										
Interim Enhanced Surface Water Treatment (R-20-01)	X	X	U	.	.	.	.	.	.	.
Perchlorate MCL (R-16-04)	X	X	U	.	.	.	.	.	.	.
Arsenic MCL (R-17-04)	X	X	.	.	.	.	.	.	.	.
Waterworks Standards (R-14-03)	X	X	.	.	.	.	.	.	.	.
Cross Connection Control	.	.	.	.	.	.	.	.	.	.
Recharge/Reuse	.	.	.	.	.	.	.	.	.	.
Treatment Device Certification	.	.	.	.	.	.	.	.	.	.
Chromium-6 MCL	.	.	.	.	.	.	.	.	.	.

Go to Drinking Water Regulations
Go to Recycled Water Regulations
Return to DDWEM

http://www.dhs.ca.gov/ps/ddwem/publications/Regulations/statusofregulations.htm

Appendix B

Survey of Municipal Water Suppliers For Pacific Gas & Electric Company's Energy Baseline Survey

Date: _______________________ Interviewer's initials: _______________

Contact Information

Name of the Public Water System: ____

Facility Name: ____

Facility Address: ____

Name of Person Completing Survey: ____

Phone: _______________________________ E-mail: ______________________________________

Plant History

The plant was originally constructed in, approximately, what year? __________

Who was the design firm? If there have been major upgrades of the plant, who were the design firms that completed the most recent major upgrades?

Treatment Technology Modified/Added Year Design Firm

A. ____

B. ____

C. ____

Do you have information about the capital cost for the disinfection system? ____ If so, what information about the capital cost can you provide? ___________________________________

Plant Characteristics

Approximately:

1. What is the design flow rate (million gallons per day - MGD)? __________

2. What is the current annual average flow rate (million gallons per day – MGD)? __________

3. Approximately what percentage of flow is from:
    a. surface water? (%)__________
    b. ground water? (%) __________

4. Approximately, how many connections do serve? ________________________________

5. What treatment is provided to the raw water <u>before</u> it comes to this plant? ____________

Sand filtration _____	Carbon filtration ____
Coagulation ____	Flocculation ____
Chlorine disinfection ____	Chlorine Dioxide disinfection ____
Ultraviolet radiation _____	Other ____________________________________

(Other disinfection methods could include use of: chloramines, iodine or bromine)

6. What treatment(s) is(are) provided to the flow <u>at</u> this plant?

Sand filtration _____	Carbon filtration ____
Coagulation ____	Flocculation ____
Other ___________________________________	Chlorine gas disinfection ____
Sodium hypochlorite ____	Chlorine Dioxide disinfection ____
Ultraviolet radiation ____	Ozonation ____
Membrane filtration ____	Type of membrane filtration _________________

7. Approximately, how many years has the current method of disinfection been used at this plant? _____

8. If multiple methods of disinfection are used, why are multiple methods used?____________________
____
____

9. If the method of disinfection currently being used requires a back-up system, what is the back-up system?
____

10. What, if any, special training was required of your operations staff in order to operate your disinfection system?
____
____
______

11. Does the supervisory staff need any special training to oversee the disinfection process? Please describe that training.
____
____
_____

12. If the method of disinfection currently being used is different from the method in the original design, what was the original method of disinfection? ____________________________. Why was the method of disinfection changed?
____

16. Does the treated flow from the plant periodically exceed any of the National Secondary Drinking Water Regulations (NSDWRs)? ____ If so, which contaminants? ______________________________

If the answer to questions 15 and 16 is 'NO', skip to question 18.

---

17. Do you think the disinfection treatment technology contributes to the treated flow exceeding either a regulated contaminant or a NSDWR, identify which contaminant or contaminants. ____

____

18. Please rate the disinfection treatment technology(ies) used at the plant for its effectiveness in the following areas:

Area	Low	Medium	High
Removal/inactivation of microorganisms			
Removal/destruction of inorganic chemicals			
Removal/destruction of organic chemicals			
Removal of radionuclides			
Minimizing formation of disinfection byproducts			

19. Please rate the disinfection treatment technology(ies) used at the plant for in the following areas:

Area	Low	Medium	High
Reliability of the day-to-day performance			
Complexity of operating the equipment/system			
Customer satisfaction			
Safety of plant and surrounding area			

20. The Division of Drinking Water at the Dept of Health Services is developing new regulations on disinfection and disinfection by-products. Do you have preliminary thoughts as to how you will comply with the regulations under development? ____

____

21. Are there plans to change the current disinfection treatment technology? _____ If so, what are the main considerations for making the change? ____

---

22. Have space constraints influenced your selection of disinfection technique? Do you expect space constraints to affect selection of treatment technique in the future?________________________________

25. Have the plant operations been adjusted to reduce the peak demand and to reduce electrical demand during the electric utility's peak period (such as filling reservoirs at night)? ______
Briefly describe those measures: ____
____
____

26. Does the plant pressurize a large percentage of its flow in order to serve a small percentage of customers who are a higher elevation? ______________________

27. Does the plant have an instrumentation and control/SCADA system? ____ Is the system being used? _______ Is power consumption monitored or trended? _______ Is monthly energy consumption data available? ____ Can we have the data for the previous 12 months?___

28. Has an energy audit of your plant operations been conducted within the last 5 years? ____
What cost-effective efficiency measures were identified? _____________________________
____

29. Have any of the above or other energy efficiency measures been implemented? ______
If so, which measures were implemented? ____
____
____

30. Please indicate why other measures were not implemented. __________________________
____
____

31. Do you have information about O&M costs for the disinfection system? __________
What information can you provide about your O&M cost? _________________________

32. When you have expansion or retrofit projects, is energy efficiency one of your considerations? ____ If so, do you:
Rely on the design firm _____
Use in-house staff to assess the efficiency _____
Retain an independent consultant to review the design ______
Utilize programs available through PG&E ______
Other: ____
____

33. Are you aware there are energy efficiency programs available to your utility through PG&E?
____

34. Have you used PG&E energy incentive programs when expanding or retrofitting your plant?
If so, what project(s)? ____
____

Thank you for your time.

List of Agencies Contacted

Sites and Agencies Contacted	
Provided Information	
San Francisco Public Utilities Commission	Sunol Filtration Plant
	Harry Tracy Filtration Plant
San Jose Water Company	Montevina Filter Plant
	Saratoga
Sonoma County Water Agency	Wohler
	Mirabel Chlorination Facility
	Cotati Facility
Placer County Water Agency	Bowman Auburn
	Foothill
	Alta
Contra Costa County Water System	Randall Bold Water Treatment Plant
	Bollman Plant
East Bay Municipal Water District	Sobrante
Stockton East Water Agency	Stockton Water Plant
No Information	
Fair Oaks Water District	
Alameda County Water District	
Fresno Department of Public Utilities	
Marin Municipal Water District	
Mid Peninsula Water District	
North Marin Water District	
San Luis and Delta-Mendota Water Authority	
Santa Clara Valley Water District	
Santa Cruz City Water Department	
Santa Rosa Water Department	
Vacaville Water	